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Journal
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Vol. 7 FEBRUARY, 1923 Number 2

NOTE ON THE PRINCIPAL REFLECTING POWERS OF TELLURIUM

By L. P. Sieg

In a recent paper, Van Dyke[1] has published data giving the principal optical constants of isolated tellurium crystals. These data were obtained by reflecting plane polarized light from one of the six panel faces of an hexagonal crystal at azimuth 45°, with various angles of incidence, and determining by analysis of the reflected elliptically polarized light, the principal optical constants. In his experiments the crystal was placed successively in the first and second principal positions, the former with the principal crystalline axis perpendicular, and the second with the axis parallel to the plane of incidence. With results from these two principal positions, employing various angles of incidence, the disentangling of the various optical constants becomes simply a matter of carrying through the solutions of numbers of pairs of complex equations. Just as has been pointed out[2] for the analogous selenium crystals the results thus obtained are apparently satisfactory, but the computations are so detailed, and so many assumptions are made throughout the discussion leading to the final working equations, that one feels that direct experimental evidence ought to be obtained to check, as far as possible, the data indirectly calculated. The task of checking directly the principal indices and the principal absorption constants seems well nigh insuperable, but the reflecting powers, on the other hand, are quite easily determinable by direct means.

By the use of the same apparatus[3] employed for testing selenium crystals, a direct determination has been made of the principal reflecting

[1] Van Dyke, J. O. S. A. & R. S. I., *6*, p. *917*, *1922*.
[2] Sieg, J. O. S. A. & R. S. I., *6*, p. *448*, *1922*.
[3] Sieg, *loc. cit.*, p. *457*.

powers of a number of tellurium crystals for a range of wavelengths in the visible spectrum. The results, together with VanDyke's similar data are shown graphically in Fig. 1. The principal reflecting powers refer to the action of the crystal to normally incident plane polarized light with the electric vector parallel and perpendicular respectively to the principal crystalline axis. As was pointed out in discussing the results for selenium, there is present in these experiments a rather large experimental error due largely to the necessity of matching fields of light of very low intensity. Many independent

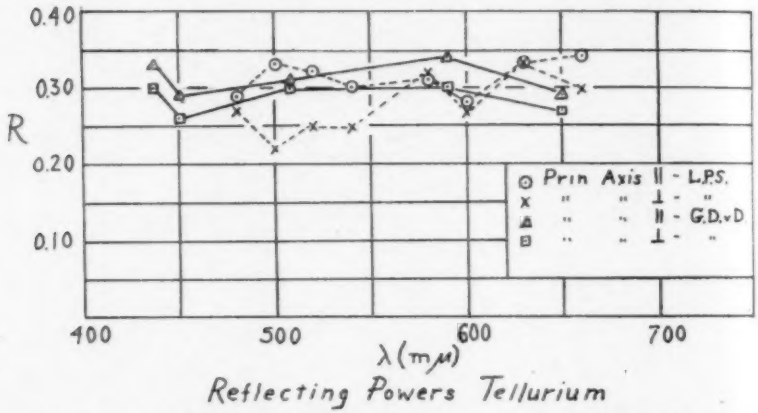

FIG. 1. *The principal reflecting powers of tellurium. Those obtained by direct experiment are indicated by the dotted lines; those obtained by an indirect method, by full lines.*

experiments, however, give average results that are fairly satisfactory. It will be noted in the figure, that my data in general agree very well with those of VanDyke,[4] and further, that the two reflecting powers are very close together. These data compare as to their average values very closely with those from selenium, but the latter are separated by a considerably wider interval.

It is now felt as a result of these direct experiments on selenium and tellurium, that in future the results of the indirect method may be relied upon, without the necessity of direct checking. These direct experiments are very tedious, and yield only the reflecting powers, while the polarimetric method yields all three sets of optical constants.

[4] The data of the present experiments are indicated in the legend on the figure by the initials L. P. S. VanDyke's data are indicated by G.D.v.D.

For exploration in the ultra violet (which investigation is now under way) there is no simple way of making direct tests. It is hoped to carry through a rather extensive program of determinations of optical constants of as many elementary substances as possible, these substances to be in the form of isolated crystals.

UNIVERSITY OF IOWA,
NOVEMBER, 1922.

Reflection Power of Stellite and Lacquered Silver.—W. W. Coblentz and H. Kahler have shown that the reflectivity of stellite varies somewhat in the visible spectrum, depending upon the homogeneity and no doubt upon the exact composition of the alloy.

Data are given on the reflecting power of lacquered silver mirrors, before and after exposure to ultraviolet light. It is shown that owing to photochemical action in the lacquer, the silver is turned brown in color, thus reducing its reflecting power. (Bureau of Standards, Sci. Paper No. 342.)

Practical Spectrographic Analysis.—Meggers, Kiess, and Stimson have published a brief review of various methods which have been proposed for chemical analyses by means of the spectrum, followed by a detailed description of the principle, apparatus and procedure employed in making quantitative analyses from the spectra of condensed sparks. The principle is based on the well known fact that if one examines the spectra of flames, arcs, or sparks, either visually or photographically, it is seen that with the diminution of an element in a mixture its spectrum becomes simplified, more and more lines disappear, so that in general only one extremely sensitive line remains when a minute trace of the element is present. From a study of standard samples whose chemical composition is known, the partial spectrum of each element may be correlated with the amount present, thus furnishing a basis for estimating the composition of impure materials. Such tests have the widest application and are best controlled and interpreted when the materials are made luminous in a high potential capacity spark and the spectra of standard and unknown samples are photographed for comparison. The practical application of this method is illustrated by three examples taken from the work of the spectroscopy section of the Bureau of Standards. They deal with the quantitative determination of impurities in various samples of tin, gold, and platinum. This spectrographic method of analysis is especially sensitive and useful in nearly all cases where small quantities of samples or impurities are to be tested and can therefore be used to advantage in supplementing assays or the wet methods of chemical analysis which in many such cases are difficult and uncertain. For routine work of this nature a standardized spectrographic method will furnish results of considerable accuracy and will reduce the time and expense involved in the more tedious methods. Other applications to problems in chemistry, metallurgy, mineralogy, physics, biology, etc., are suggested. (Bureau of Standards, Sci. Paper No. 444.)

THE REFLECTION OF ULTRAVIOLET BY FLOWERS

By F. K. Richtmyer

The investigation which forms the basis of the present paper is part of a larger problem undertaken by Dr. F. E. Lutz and the writer with assistants, under the auspices of the Committee on the Biological Relations between Flowers and Insects appointed by the Division of Biology and Agriculture of the National Research Council. This Committee consists of Dr. F. E. Lutz,[1] Curator of the Department of Entomology of the American Museum of Natural History, Chairman; Dr. J. Arthur Harris, of the Station for Experimental Evolution at Cold Spring Harbor; and the present writer. The work, which was done in Colorado during the summer of 1922, was supported by grants from the National Research Council, from the American Museum of Natural History, and from the Heckscher Research Fund of Cornell University.[2]

THE PROBLEM

The full report of the Committee will be published elsewhere at a later date. Suffice it for the present to say that one of the problems to which the Committee turned its attention was the question of what part, if any, is played by ultraviolet light in attracting insects to flowers. Many students of evolution have held the view that the colors common to most flowers serve to attract insects, which, in gathering nectar and pollen, carry pollen from one flower to another, thereby causing fertilization. This assumes first that flower-visiting insects see colors much the same as humans do, and second, that insect psychology is similar to human psychology in that brilliant colors are attractive.

With regard to the first assumption, no data exists—indeed it would be difficult to get—to show that insects *see* color as distinguished from and in addition to brightness. Further there is no reason to expect, *a priori*, that insect vision should be confined within the spectral limits

[1] To Dr. Lutz is to be given credit for the organization of the Committee, for planning the field work for the summer of 1922, and for valuable suggestions concerning the investigation herein reported. F. K. R.

[2] To this Fund the writer acknowledges, with thanks, his indebtedness for an appropriation to cover certain necessary supplies, and a portion of his expenses.

.39 to .78μ as is human vision. Some data exists[3] to show that insects are more sensitive to the blue and violet end of the spectrum than are human beings. And since it is well known that the sun's spectrum, as it reaches the earth's surface after penetration through our atmosphere extends from far in the infra-red down to .305μ, where it is very sharply cut off, apparently by absorption, it may very well be that insects, in the process of evolution, developed a light receptive mechanism sensitive farther into the ultraviolet than .39μ which marks (about) the limit of sensitivity of the human eye. Should this be so, it is evident that ultraviolet would play an important part in flower visitation, provided that flowers reflect a considerable proportion (varying, of course, from one flower to another) of ultra-violet, as is the case in the visible region of the spectrum.

The effect of ultraviolet in flower visitation by insects, then, involves two questions: (1) Do insects "see" ultraviolet in the sense that, as we have every reason to expect, they "see" the visible (ruling out the phenomenon similar to corneal fluorescence in humans)? And (2) is the ultraviolet reflected by flowers in sufficient amount to play any important part in making flowers visible to insects?

No systematic study of the ultraviolet sensitivity of insects has ever been made. But several papers have been published showing that some insects, at least, respond to ultraviolet. Thus Kühn and Pohl[4]

[3] A very large number of papers—one authority states 5000—has been written on the vision of insects and its relation to flowers. The following references, kindly furnished to the writer by Dr. Lutz, are representative and will serve as an introduction to the rather extensive literature on the subject:

Lubbock, Sir John: "On the Senses, Instincts, and Intelligence of Animals, with special Reference to Insects."
Appleton and Company (New York). 1888.

Hess, C.: "Gesichtssinn" in Winterstein's "Handbuch der vergleichender Physiologie." *4*. (Gives bibliography); 1913.

Demoll, Reinhard: "Die Sinnesorgane der Arthropoden, ihr Bau und ihre Funktion." Vieweg and Sohn. (Braunschweig), 239 pp., including bibliography; 1917.

Eltringham, H.: "Butterfly Vision." Trans. Entomological Soc. London, pp. 1–49; 1919.

v. Frisch, K.: "Über der Geruchsinn der Bien und seine blutenbiologische Bedeutung." Zoologische Jahrbücher, Abt. Allg. Zool. Physiol. *37*, pp. 1–238; 1919.
(Gives bibliography of experiments on color-vision also.)

Kühn, A., and Pohl, R.: "Dressurfähigkeit der Bienen auf Spektrallinien." Die Naturwissenschaften, *37*, pp. 738–740; 1921.

[4] "Dressurfähigkeit der Bienen auf Spektrallinien." Naturwissenschaften, *9*, p. 738; 1921.

show that bees can be trained to go to any spectral line of the mercury arc, including the line .3650μ. And Dr. Lutz and the writer showed[5] that Drosophila (melanogaster) is sensitive to the ultraviolet part of a spectrum obtained by passing light from an ultraviolet generator through a quartz spectrograph. However, so far as the writer is aware, no data exists on the reflection of ultraviolet by flowers. And it seemed desirable to the above Committee, that, in connection with entomological and botanical field work proposed for the summer of 1922, simultaneous observations on insect visits and ultraviolet reflection should be made. Because of the wealth of its insect fauna—Dr. Lutz and Professor Cockerel have listed some eight hundred varieties of wild bees in Colorado alone—and because of freedom of both flora and fauna from contamination by European or Asiatic importations, Colorado was chosen as the place to make the observations.

Apart from its relation to the biological factors involved, this data on the reflection of ultraviolet by flowers is of only minor significance —at least so far as *physical* science is concerned. Yet separate presentation seemed worth while if for no other reason than to call to the attention of those whose main activity lies in the physical sciences, the importance of and the opportunity for cooperative investigations in the field of biophysics.

METHOD AND DATA

Since only qualitative, or roughly quantitative, results were desired a very simple method was chosen. A small, portable, quartz spectrograph, giving a spectrum 1.6 cm long from $\lambda = .30\ \mu$ to $\lambda = .50\ \mu$ was used to get on the same plate and under, so far as was possible, the same conditions of *daylight* illumination, a spectrogram of a magnesium oxide surface (arbitrarily chosen as a standard of comparison) and several spectrograms, of increasing length of exposure, of the flower in question, in daylight. The slit of the spectrograph was sufficiently narrow (approximately .03 mm wide) to resolve clearly the Fraunhofer lines, which served conveniently as a means of identifying wavelengths. The flower was held in position during the exposure by a small clamp attached to a ½ inch steel rod driven into the ground near the stem of the plant.

The apparatus, flower and spectrograph, was protected from the direct rays of the sun by means of a small screen of white cloth placed

[5] Science, *55*, p. 519; 1922.

some two feet above the flower. Thus the flower, during exposure, received diffuse light from the sky and surrounding objects. From the standpoint of precise measurements the illumination on the flower probably varied somewhat during the series of exposures, due to shifting clouds, change of position of sun and of nearby shadows, etc. This variation was, however, well within the limits of error of the observations, and since exposures were taken only when the sun was entirely free from drifting clouds, it may be assumed that all exposures of a series were taken under constant illumination.

The method of taking data and of interpreting spectrograms is shown in Fig. 1.* This is the plate of petalostemon purpureus, or pink prairie

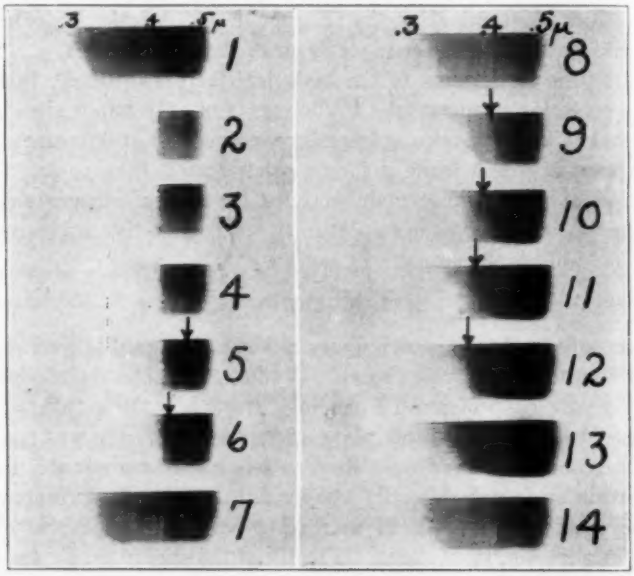

FIG. 1. Illustrating the method of taking and working up data.

clover, reproduced about twice original size. Spectrograms 1, 7, 8, and 14 are of the standard magnesium oxide plate. The remainder are of the petalostemon. The wave length scale is shown on only one. The times of exposure of all the spectra are given in column 3 of Table 1.

A glance at the spectra shows that, as compared with the magnesium oxide surface, the petalostemon reflects very little ultraviolet. Thus,

in spectrum 4, petalostemon for 12 seconds, at no point is the blackening of the plate as great as at the corresponding point in spectrum 1, magnesium oxide for 6 seconds. In other words, from the ultraviolet up to about .50 μ (end of spectrum) the coefficient of reflection of the petalostemon, relative to magnesium oxide, is less than 50 per cent. In

Exposure	Subject	Duration	Reflection at equality with standard	λ at equality
1	magnesium	6 sec.		
2	flower	6	100%	
3	"	9	67	
4	"	12	50	
5	"	18	33	.45μ
6	"	24	25	.41
7	magnesium	6		
8	magnesium	6		
9	flower	30	20	.395
10	"	60	10	.385
11	"	150	4	.38
12	"	300	2	.37
13	"	600	1	
14	magnesium	6		

spectrum 5, however, at the point marked by the arrow, $\lambda = .45\ \mu$, it is seen (on the original plate) that the blackening is about equal to that at the same point on the magnesium oxide spectra. This exposure was 18 seconds, three times the standard. *At this wave length*, therefore, the light reflected from the flower is one third as intense as that reflected from magnesium under the same conditions of illumination. That is, the coefficient of reflection of the petalostemon at $\lambda = .45\ \mu$ is 33 per cent of the standard. This is shown in columns 4 and 5 of the table.

Referring to exposure number 6, 24 seconds, the blackening at $\lambda = .45\ \mu$ is greater than at $\lambda = .45\ \mu$ on the standard. But at $\lambda = .41\ \mu$ the blackening seems to be the same. Since the exposure is four times as long as the standard, this gives for .41 μ a relative coefficient of reflection of 25 per cent. In a similar way the coefficient of reflection at other wavelengths is determined.

The data is shown graphically in Fig. 5 B, in which wavelength is plotted as abscissae and coefficients of reflection, relative to magnesium oxide as a standard, as ordinates. In this particular flower, two com-

pletely independent plates were taken. These were independently "worked up" as described above. One set is shown by circles; the other by crosses. It is seen that the precision, while not high, is of the order of 10 to 20 per cent—ample for the preliminary survey which it was intended to make.

In this way data was taken on the ultraviolet reflection of some thirty Colorado flowers and one yellow spider. At first, spectrograms were made without removing the flower from its stalk. But it was later found that, within the limits of error attainable, it made no difference whether the flower was on the stem or was cut, provided it was immediately put in water. Hence, toward the latter part of the work, cut flowers were used exclusively, because of the greater ease of arranging apparatus.

The following is a list of flowers studied, arranged in the order in which, for convenience, they were plotted: The terminology is that of Clemens:[6]

Monarda Fistulosa. (Horse mint or Bee balm.) Fig. 2 A. Color, medium rose purple. Growing in partial shade. Altitude 6500 feet. Flowers form a rather loose head or cluster. To obtain a sufficiently colored area at which to point the spectrograph, a head or cluster of flowers was bunched together by a rubber band. Spectrograph was pointed at side of bunch rather than at center. On stalk.

Laciniaria punctata. (Blazing Star). Fig. 2 B. Color, brilliant rose purple. Growing in open field. Altitude about 7500 feet. Flowers form a rather irregular spike. Spectrograph was pointed along axis of spike, slightly displaced from center. Cut. (Unfavorable weather necessitated keeping flower in water 24 hours before obtaining spectrograms.)

Frasera speciosa. (Green Gentian). Fig. 2 C. Color, whitish green. Growing in open . Altitude 7000 feet. Spectrograph was pointed slightly off center of flower with axis of slit making angle of about 45 degrees with axis of two adjacent petals. On stalk.

Campanula rotundiflora. (Blue bell or Hare bell). Fig. 2 D. Whitish blue. Altitude 6500 feet in partial shade. Bell shaped flower, with edge of petals darker than center. Spectrograph

[6] The writer is indebted to Mrs. Richtmyer for much assistance in locating, obtaining and identifying a number of the flowers studied. Similar acknowledgment is also made to Dr. Lutz and Mr. Jackson.

pointed toward *side* of the inside of bell. Cut and spectrogram taken immediately.

Gentiana serrata. (Fringed gentian). Fig. 2 E. Deep blue. Altitude 9500 feet, growing in open. Flower almost cylindrical with petals slightly spreading at top. Spectrograph pointed at outside of cylinder, axis of slit parallel to axis of flower. Cut and kept 36 hours, flower retaining fresh appearance.

Delphinium scopulorum. (Larkspur). Fig. 2 F. Very dark blue. Altitude 10000 feet, growing in shade. Spectrograph pointed at body of a single flower rather than at cluster. Cut and kept 36 hours.

Geranium caespitorum. (Wild geranium). Fig. 2 A. Purplish pink. Growing in partial shade, at 6500 feet. Spectrograph pointed at single petal, axis of slit parallel to axis of petal. On stalk.

Geranium Richardsonni. (Wild geranium). Fig. 3 B. White (slightly yellowish as compared with magnesium oxide). Growing in partial shade at 6500 feet. Spectrograph pointed at single petal, axis of slit parallel to axis of petal. On stalk.

Onagra biennis. (Evening primrose). Fig. 3 C. Light yellow. Growing in open at 6500 feet. Taken on stalk at 9 A. M. Flower had started to close and was propped open with a small stick. Spectrograph pointed toward inside of petal.

Solidago missouriensis. (Dwarf goldenrod). Fig. 3 D. Golden yellow. Partial shade at 6500 feet. Flowers "bunched" by a rubber band and spectrograph pointed at center of bunch. Spectrograms made immediately after cutting.

Misumena Vatia. (A yellow spider). Fig. 3 E. This spider is frequently found on Golden Glow and it was thought that it might be of interest to compare a spectrogram of it with that of the flower (Fig. 4 B).

Ratibida columnaris. (Cone flower). Fig. 4 A. Petals, golden yellow. Growing in open at 5500 feet. Spectrograph pointed at center of a single petal. Taken on stalk.

Rudbeckia laciniata. (Wild golden glow). Fig. 4 B, (1) and (2). Petals yellow. Growing in partial shade at 6500 feet. Data taken on (1) base of petal and (2) tip of petal. Taken on stalk, but cut flower, taken later, gave identical spectrograms.

Leaf of Rudbeckia laciniata. Fig. 4 B (3). Fresh leaf spectrographed on stalk containing flowers in full bloom. Spectrograph pointed at center of leaf.

Helianthus annuus. (Wild sunflower). Fig. 4 C, (1), (2) and (3). Petals yellow; center dark brown. Growing in open at 5500 feet. Data taken on (1) base of petal; (2) tip of petal; (3) center. On stalk.

Helianthus (cultivated). Fig. 4 D. A rich maroon developed by Mrs. T. D. A. Cockerell and growing in open garden at 5500 feet. Center of petal. Taken on stalk.

Grindelia squarrosa. (Gumweed). Fig. 4 E, (1) and (2). Petals yellow; center orange yellow. Growing in shade at 6500 feet. In (1) spectrograph was pointed at base of petals, axis of slit at right angles to petals, and slit covering several petals. In (2) spectrograph was pointed directly at the compact center. Cut and spectrographed immediately.

Petalostemon compactus. (Prairie clover). Fig. 5 A. White. Growing in open at 5500 feet. Flowers form a cylindrical shaped head. Spectrograph was pointed at side of cylinder, slightly to one side of center, axis of slit parallel to axis of cylinder. Spectrographed on stem just after a shower.

Petalostemon purpureus. (Prairie clover). Fig. 5 B. Rose pink. Growing in open at 7500 feet. Flowers similar to Petalostemon compactus. Spectrograph pointed at side of cylindrical head, slightly off center. Specimen cut and kept in water 24 hours, during which time fresh flowers developed, forming a broad ring near tip of head. These were used in making the plates.

Clematis ligusticifolia. (Virgin's Bower). Fig. 5 C. White petals, yellow center. Growing in open at 6500 feet. Since flowers are too small to spectrograph individually, a bunch of them was held together compactly by a rubber band. Spectrograph was pointed at center of bunch. Two sets of spectrograms were taken: one with flowers on stem and one on cut flowers. Curves were identical.

Argemone platyceras. (Prickly poppy). Fig. 5 D. Pure white petals, very large; pistils and stamens rather prominent, forming a yellow center. Growing in open at 6500 feet. Flower was cut from stalk, but when put in shade to spectrograph, petals tended to close. Hence several petals were removed in order to expose the inside of one, at which spectrograph was pointed.

Trifolium repens. (White clover). Fig. 5 E. White. Growing in shade at 6500 feet. The head was made more compact by a rubber band and the spectrograph was pointed at the center of the bunch. Cut flower used.

Eriogonum umbellatum. Fig. 6 A. Sulphur yellow. Growing in partial shade at 6500 feet. The small flowers on a single stem were bunched together by a rubber band. Spectrograph was pointed at center of bunch. Cut flowers used.

Polygonum bistorta. (Mountain buckwheat). Fig. 6 B. White. Growing in open at 11 000 feet. Flowers form a cylindrical head at the center of which the spectrograph was pointed. Cut and kept in water 18 hours.

Acerates viridiflora. (Milkweed family). Fig. 6 C. Green flowered Growing in open at 5500 feet. Spectrographed on stem, the flower head being kept in motion during exposures in order to get an average value.

Solanum rostratum. (Buffalo burr. Wild potato flower). Fig. 6 D. Yellow. Growing in edge of city lawn at 5500 feet. Spectrographed on stem.

Achillia millefolium. (Yarrow). Fig. 6 E. White. Growing in shade at 6500 feet. A bunch of flowers was made more compact by rubber band. Spectrograph pointed at center of bunch, flowers on stalk.

Castilleia pallida occidentalis. (Painted cup). Fig. 6 F. Red. Growing in open at 11000 feet. Spectrograph pointed at side of spike. Cut flower, kept in water 36 hours.

Althea rosea. (Hollyhock). Fig. 6 A, white; B, yellow; C, red; D, deep brown. A group of hollyhocks growing in a city garden at 5500 feet. Flowers were spectrographed on stalk, the spectrograph being pointed at the inside of the cup toward a region of characteristic color.

CONCLUSIONS

The limited quantity of data obtained and its comparatively low precision prohibit the drawing of any very rigorous conclusions. But such as it is, the data seems to point to a few generalizations, which, however, must depend on further work in this field for confirmation. They are recorded here simply as suggestions to subsequent investigators.

1. Few flowers reflect any considerable proportion of ultra-violet. Of the twenty-five flowers studied only four reflect more than ten per cent of radiation shorter than .38 μ. These are: Laciniaria punctata (Fig. 2 B); Onagra biennis (Fig. 3 C); Rudbeckia laciniata (Fig. 4 B); and Solanum rostratum (Fig. 6 D).

2. Certain yellow flowers show a distinct ultraviolet reflection band. (Figs. 3 C, 4 B and 6 D.) The reflection band in Rudbeckia is particularly well marked on the plates. Other yellow flowers, such as Solidago (Fig. 3 D) and Ratibida columnaris (Fig. 4 A) show no trace of such a band. Rudbeckia is particularly interesting. Were the human luminosity curve to be extended proportionately toward shorter wave lengths so that it stopped at .3 μ instead of .4 μ, the color of Rudbeckia would be purple instead of yellow.

3. Flowers differ from each other in their reflection of ultraviolet just as much and in just as erratic ways as is the case in the visible spectrum. A white flower is white because it reflects, in approximately equal proportions, all the colors of the visible spectrum. One might expect, apriori, that it would reflect also a considerable proportion of ultraviolet. That this is not the case is illustrated by the curves shown in Fig. 5. Excepting B, all these are white flowers, showing high reflection of light longer than .42 or .43 μ. None of them, however, reflect more than 4 per cent of .39 μ. The most striking case is that of Argemone platyceres (Fig. 5 D). At .41 μ the relative coefficient of reflection of this flower is more than 75 per cent. At .39 μ it is 4 per cent.

This difference in ultraviolet reflection, even among flowers which reflect only a small amount of ultraviolet, is strikingly illustrated on some of the original plates, two of which are reproduced in Fig. 8. Fig. 8 A shows a series of exposures on the petals of Grindelia squarrosa. (Curve shown in Fig. 4 E.) Exposures 1 and 7 are on the standard, magnesium oxide, each six seconds. Exposures 2, 3, 4, 5 and 6 are on the flower for 6, 9, 12, 18 and 24 seconds respectively. These show that the flower reflects an appreciable proportion of ultraviolet, although the intensity of spectrum 6 (exposure four times the standard) from .33 μ up to .55 μ is at no point as great as that of the standard. Fig. 8 B shows a similar series of exposures for Argemone platyceras, (Curve shown in Fig. 5 D). Spectrum 2 (exposure six seconds on flower) is, in the visible, nearly as intense as the corresponding part of the standard; but an exposure four times as great (number 6) fails to bring out even a trace of ultraviolet.

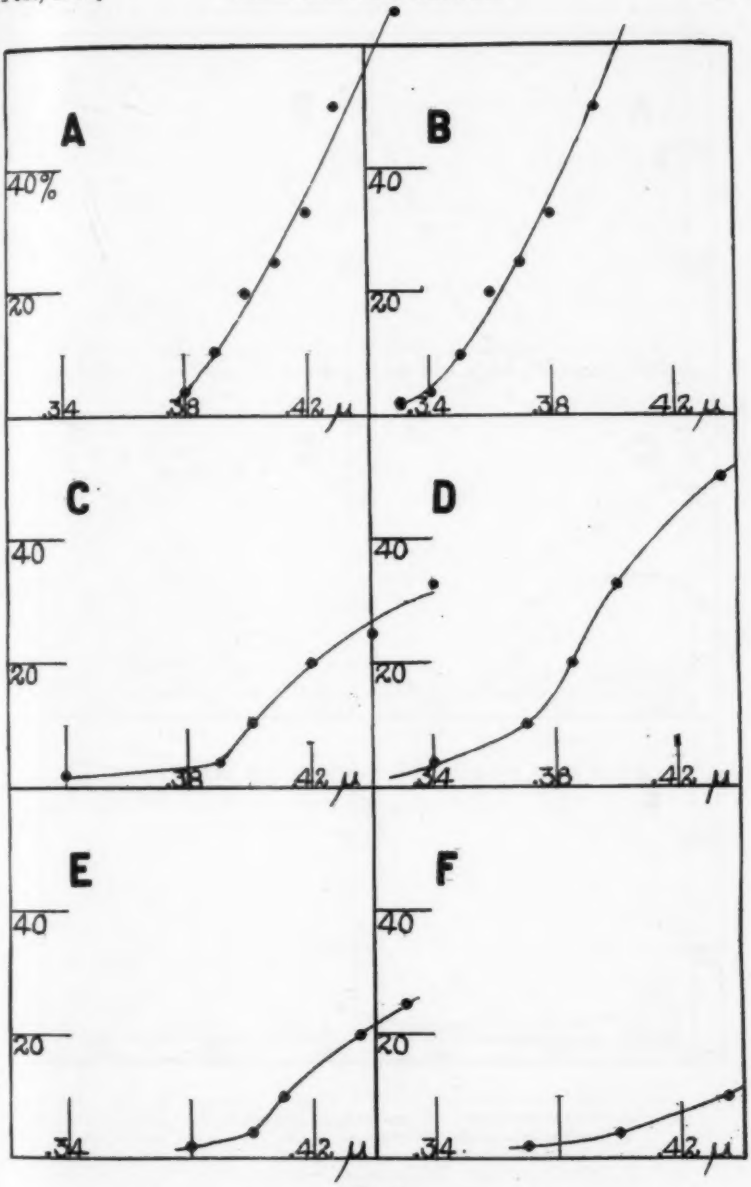

FIG. 2

A. Monarda fistulosa. Horse mint. (rose purple.)
B. Laciniaria punctata. Blazing star. (rose purple.)
C. Frasera speciosa. Green gentian. (whitish green.)
D. Campanula rotundifolia. Blue bell or hare bell. (whitish blue.)
E. Gentiana serrata. Fringed gentian. (deep blue.)
F. Delphinium scopulorum. Larkspur. (very dark blue.)

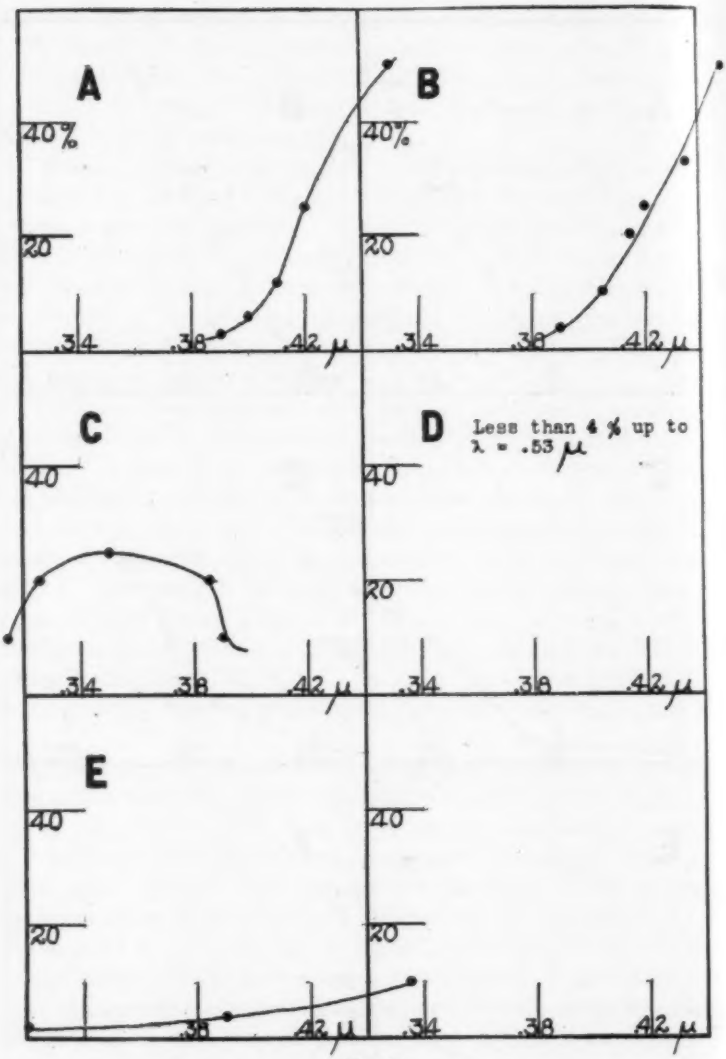

FIG. 3

A. Geranium caespitosum. Wild geranium. (purplish pink.)
B. Geranium Richardsonii. Wild geranium. (white.)
C. Onagra biennis. Evening primrose. (light yellow.)
D. Solidago missouriensi-. Dwarf goldenrod. (yellow.)
E. Misumena vatia. A yellow spider. (Body.)

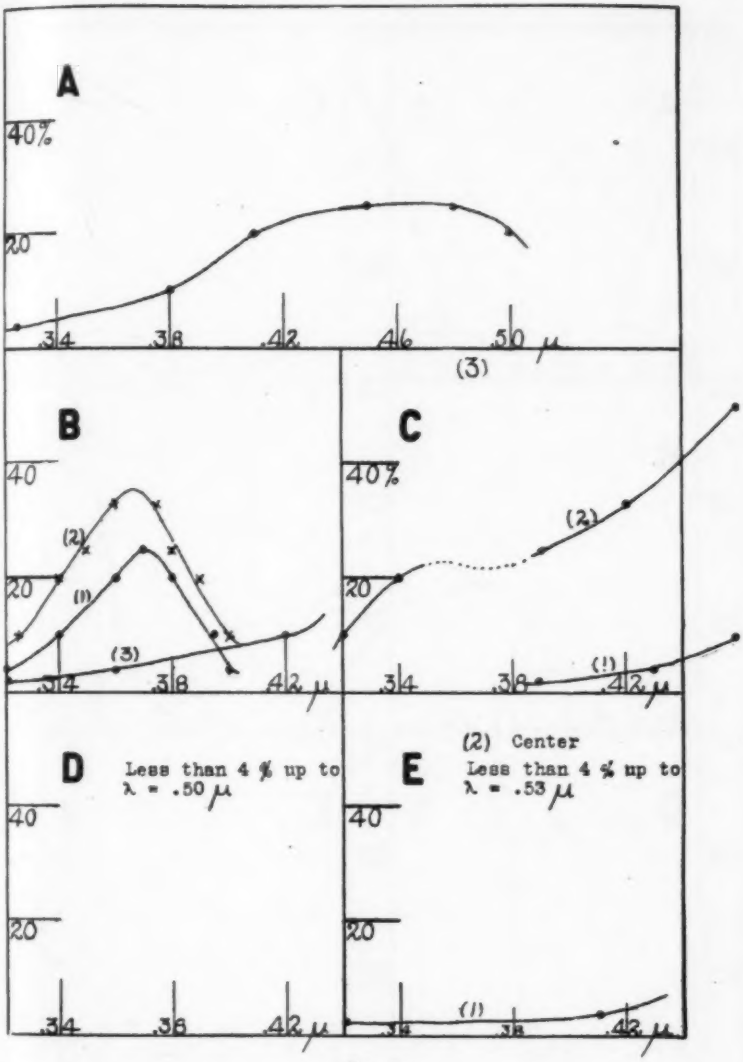

FIG. 4

A. Ratibida columnaris. Cone flower. (yellow.)
B. Rudbeckia Laciniata. Wild golden glow. (yellow.)
(1) Base of petal
(2) Tip of petal
(3) Leaf.

C. Helianthus annuus. Wild sunflower. (yellow.)
(1) Base of petal
(2) Tip of petal
(3) Center. (dark brown.)

D. Helianthus (cultivated). (rich maroon.)
E. Grindelia squarrosa. Gumweed.
(1) Petals. (yellow.)
(2) Center. (orange yellow.)

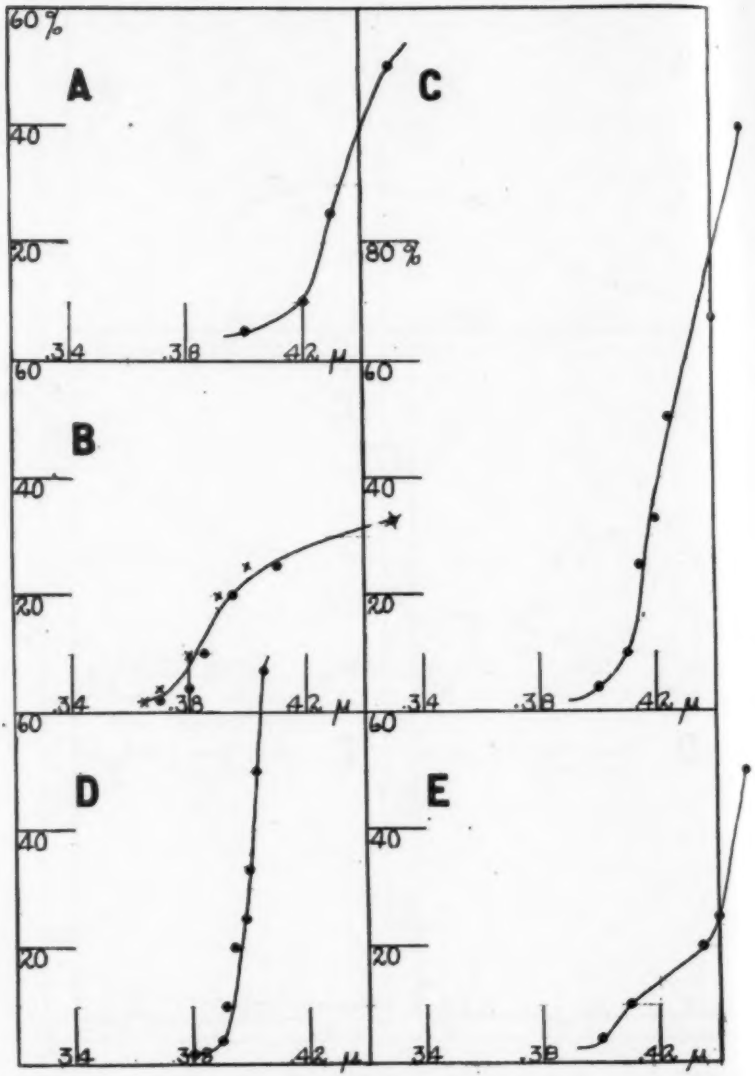

FIG. 5

A. Petalostemon compactus. Prairie clover. (white.)
B. Petalostemon purpureus. Prairie clover. (rose pink.)
C. Clematis ligusticifolia. Virgin's bower. (white.)
D. Argemone platyceras. Prickly poppy. (white.)
E. Trifolium repens. White clover. (white.)

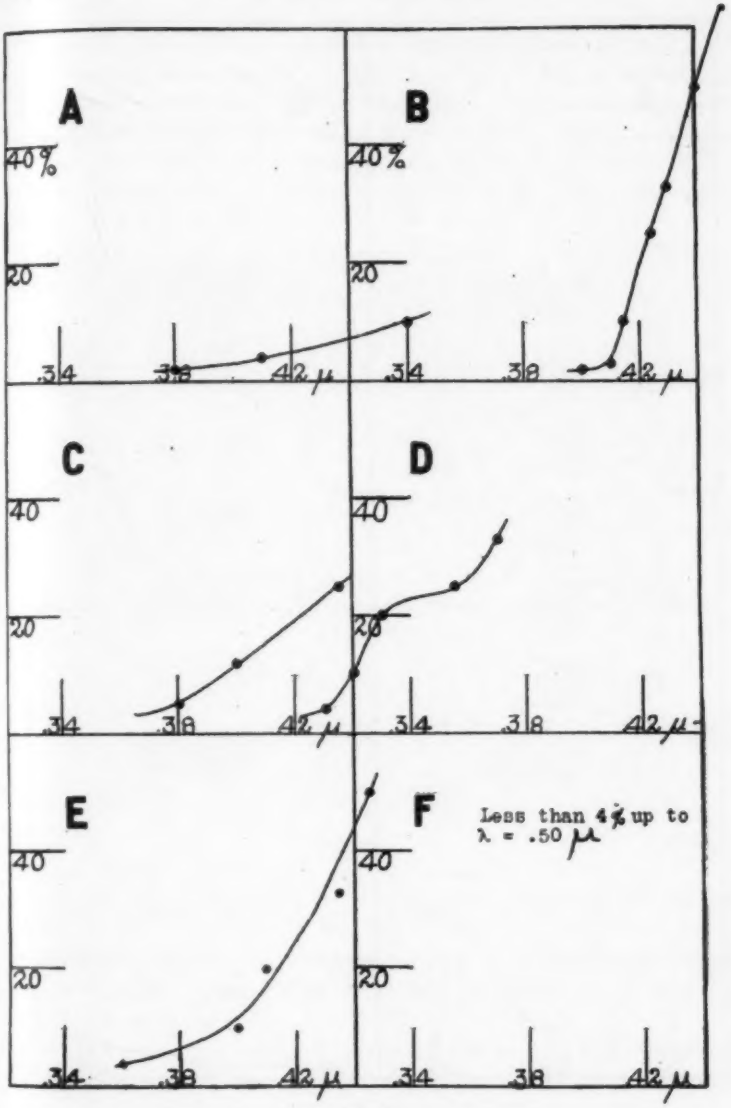

FIG. 6

A. Eriogonum umbellatum. (sulphur yellow.)
B. Polygonum bistorta. Mountain buckwheat. (white.)
C. Acerates viridiflora. (green.)
D. Solanum rostratum. Wild potato flower. (yellow.)
E. Achillia millefolium. Yarrow. (white.)
F. Castilleia miniata. Painted cup. (red.)

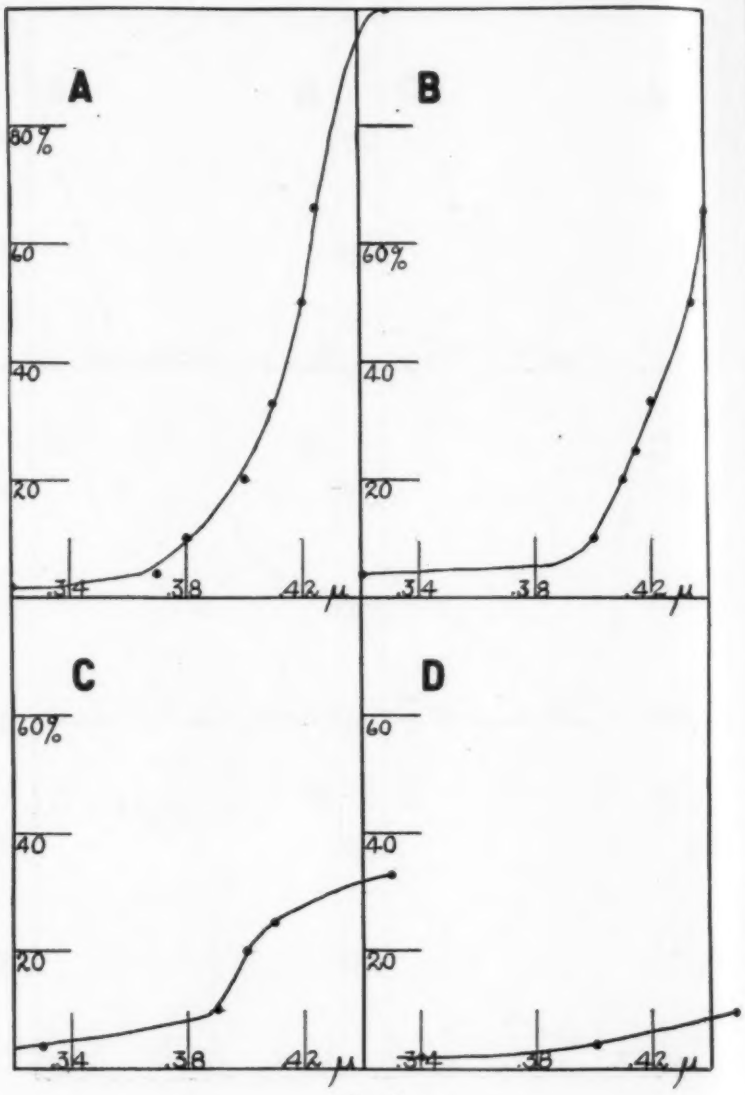

FIG. 7

Althaea rosea. Hollyhock.
A. white.
B. yellow.
C. red.
D. deep brown.

4. There seems to be no relation in respect of ultraviolet reflection among flowers belonging to a group or species. This is shown by Fig. 7, which shows four different hollyhocks. Beyond the fact that the coefficients of reflection of all of them are small—which, as previously pointed out, is not a distinguishing characteristic—there is no similarity in their curves. This is also shown in the case of the white

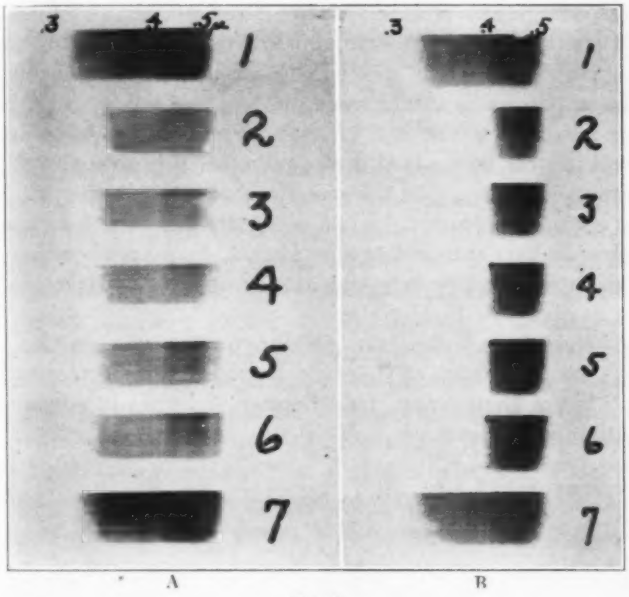

FIG. 8

Showing the difference in ultraviolet reflection of flowers.

A is a yellow flower, showing a small amount of blue, violet and ultraviolet reflection. B is a pure white flower showing a strong blue and violet reflection but hardly a trace of ultraviolet.

and the pink petalostemon. Fig. 5, A and B. On the basis of differences of reflection in the visible, we should, of course, expect no similarity in the ultraviolet.

The net result, in a word, of this work has been to raise problems rather than to solve them. A sufficient amount of data has been taken to show that a more complete study should lead to generalizations of importance. For example, do white flowers generally reflect only a small proportion of ultraviolet? What yellow flowers show a distinct reflection band in the ultraviolet? There is evidence that different

parts of certain flowers, though identical in color visually, are quite different photographically. Is this due to ultraviolet reflection? In addition to having a distinct botannical value, the answers to such questions as these would be of great assistance to the entomologist in his study of the relations of flowers and insects.

For the benefit of those who may wish to undertake work in this field, the writer wishes to suggest, as a result of his experience, that while a photographic method is the only one practicable for the ultraviolet, a modified visual spectrophotometric method is most suitable for the visible part of the spectrum. It should not be difficult to design an apparatus in which, using a total reflecting prism or first surface mirror over one half of the slit, adjacent and simultaneous spectrograms can be made of flower and standard surface for studying the ultraviolet region. In the same instrument could be embodied a visible spectrophotometer, by use of suitable mirrors, for comparing the flower and the standard surface at each wave length in the visible. Such an outfit would be independent of reasonable variations in intensity of daylight.

In conclusion the writer takes pleasure in acknowledging his obligations to the University of Colorado, particularly to Professor Lester of the Physics Department, for laboratory facilities in adjusting and calibrating instruments.

CORNELL UNIVERSITY,
SEPTEMBER, 1922.

THE INFRARED ABSORPTION OF HYDROGEN CHLORIDE IN THE REGION 3.5 μ AND AT 200° K

By B. J. Spence and C. Holley

Abstract: Considerable theory exists bearing upon the relationship between the maxima of the envelop of the double branched series of absorption bands in the near infrared for such diatomic gases as the hydrogen halides and the temperature at which absorption takes place. An attempt has been made to compare experiment and theory particularly that of Kemble,[1] and Reiche.[2] We have determined the absorption of hydrogen chloride in the region 3.5 μ at two temperatures 200°K and 291°K. The agreement of experiment with theory is good at 291°K, but at 200°K there is a slight departure.

Considerable theory has been developed during the past decade bearing in the structure of the infrared absorption bands of such diatomic gases as the hydrogen halides. In the pioneer work of Bjerrum,[3] it was assumed that a band in the far infrared and due to the rotations of diatomic gas molecules whose angular velocities were distributed according to the classical statistical mechanics was responsible for the appearance of a double band in the near infrared region. It was assumed that the atoms of the molecule could vibrate along their line of centers and that this vibration frequency so combined with the frequency of corresponding to the average energy of the rotating molecule in such a manner that a double band was produced whose maxima of absorption corresponded to the frequencies $f_o \pm f_r$. A somewhat further development of the theory by Bjerrum led to the

$$f_r = \frac{1}{2\pi}\sqrt{\frac{RT}{NJ}} \qquad (1)$$

expression where f_r is the frequency corresponding to the average energy of rotation and is assumed to manifest itself as a single band in the far infrared, R is the gas constant, N the Avogadro constant, and T the absolute temperature. It appears that the frequentcy f_r is a function of the temperature. Von Bahr[4] has shown this to be qualitatively true using some data from the low dispersion experiments of Paschen.[5]

[1] Kemble Phy. Rev. N.S. *8*, 689, 1916.
[2] Zeitschrift für Physik *1*, 283, 1920.
[3] Bjerrum, Nernst Festschrift, pg. 90, 1912.
[4] Von Bahr, Phil. Mag., S.6. *28*, p. 71; 1914.
[5] Paschen, Wied. Ann., *52*, p. 215; 1894.

Later experiments have revealed the fact that the band in the far infrared is not single but consists of a series of comparatively narrow bands and that each branch of the double band in the near infrared is due to the combination of the frequencies in the far infrared and the vibration frequency of the atoms consists also of a series of fine bands. Bjerrum (loc. cit.) to explain the serrated character of the absorption bands invoked the quantum theory assuming that the molecule is not capable of rotating with any angular velocities but with such velocities as make the energy of rotation a multiple of hf_r. His expression is

$$f_r = \frac{n\,h}{2\pi^2\,J} \tag{2}$$

This expression does not involve the temperature and the independency of the frequency f_r of the bands and temperature has been borne out experimentally.

Kemble[6] later attacked the problem raising certain objections to the Bjerrum analysis, arriving at the expression

$$f_r = \frac{1}{4\pi}\sqrt{\frac{RT}{NJ}} \tag{3}$$

From the point of view of the near infrared f_r may be regarded as one half of the frequency difference of the maxima of the envelop of the aborption bands and corresponds to the most probable frequency of rotation. On lowering the temperature of the absorbing gas the maxima of the envelop of the absorption curve become less separated for the near infrared.

Planck[7] in a later discussion of the problem made use of the continuous absorption rather than the quantum absorption and arrived at the expression similar to that of Bjerrum (loc. cit.) for the behavior of the maxima of the envelope of absorption as a function the temperature.

Reiche[8] in a discussion of rotation spectra assumed that the probability w_q of a rotation state characterized by the quantum number q, has the value

$$w_q = \text{constant}\; q\, e^{-q^2\sigma} \tag{4}$$

$$\text{where } \sigma = \frac{N\,h^2}{8\pi^2\,JRT}$$

[6] Kemble, Physical Review, N.S., *8*, p. 689; 1916.
[7] Planck, Ann. der Physik, *52*, p. 491, 1917 and *53*, p. 241, 1917.
[8] Reiche, Ann. der Physik, *58*, p. 657; 1919.

Using this distribution function and assigning value 1, 2, 3, etc. to q, he found that the maximum of absorption for 291° K, corresponded to the third band in each side of the centre, a result in accord with the data of von Bahr.

In general it may be said that the theory indicates a temperature variation of the maxima of the envelop of absorption bands of both branches of the curves for the near infrared. Some investigation of the behavior of the absorption has been carried out. Cobly and Meyers[9] have shown a shift in the maxima of the envelope for high temperatures which appears to accord with the theory. No data, however, exist for the absorption at low temperatures. The problem is of particular interest in view of the fact that the behavior of the specific heats of gases for low temperatures is not in accord with the predictions of the classical statistical mechanics. Accordingly the absorption of hydrogen chloride in the region 3.5 μ at room temperature and at a temperature of 200° K close to its liquifaction temperature 190° K was undertaken.

The experiment was carried on with a grating spectrometer whose smallest scale division corresponded to 18 degrees of arc. The grating was one with a two inch ruling and a constant .00105759 cm kindly loaned to us by Professor H. M. Randall of the University of Michigan. The receiving instrument was an especially designed radiometer of the Nichols type with vanes of phosphor bronze .13 mm wide. It had a period of 8 seconds and was remarkably free from zero drift and fluctuations due to temperature or to building disturbances. A spectrometer slit of .25 mm was used throughout the experiment.

The hydrogen chloride was made of calcium chloride and sulphuric acid and passed through a drying train into the absorption cell at atmospheric pressure. The absorption cell was of brass 7 cm in diameter and 18 cm long with a mica window at the top and a silver mirror at the bottom. The absorption of the mica was eliminated by placing a double thickness of the window mica in the path of the beam when the cell was removed from the path. The radiation from the Nernst glower was caused to retrace its path in the cell by means of the bottom mirror. The cell was placed in a large Dewar bottle and cooled with liquid air. In order to prevent the mica window from frosting, a coil of a few turns of nichrome wire was placed at the top of the cell. The

[9] Colby and Meyers, Astrophysical Journal, *53*, p. 300, 1921.

general arrangement of the apparatus is set forth in the accompanying diagram.

Results. The results of the experiment are embodied in the graph. Ordinates indicate per cent absorption of the gas obtained by taking the ratio of the radiometer deflections with the cell in the path of the beam and without it. The abscissas are spectrometer settings and are very closely proportional to wave lengths. The per cent absorption was taken for ten settings between the large divisions of the abscissa

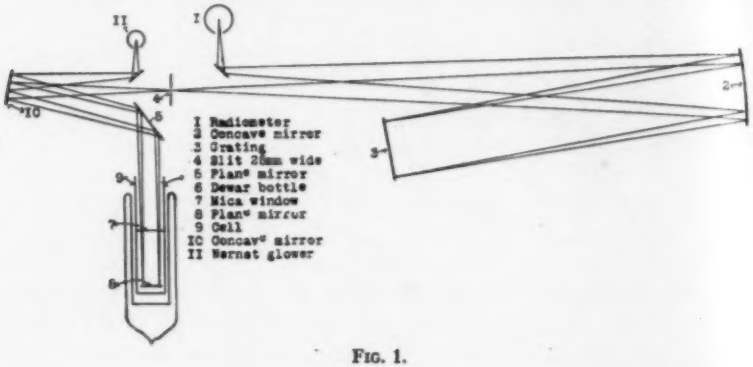

FIG. 1.

on the graph. One large abscissa on the graph corresponded to 180 degrees on the spectrometer scale. The wave lengths of the fine bands are indicated above the bands. At room temperature, 291° K the maxima of the envelop of the fine bands occur at 3.397 μ and 3.538 μ. At 200° K they occur at 3.419 μ and 3.514 μ. There appears no shift of the wave lengths of the fine absorption bands as a function of the temperature, a result in accord with the theory.

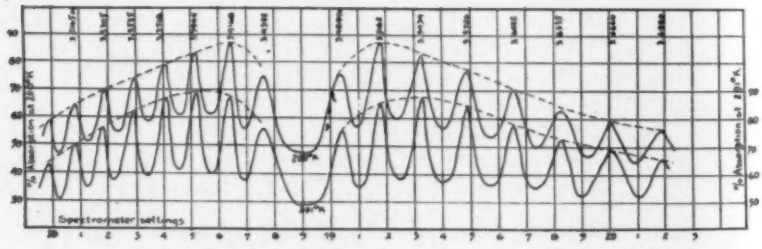

FIG. 2.

Discussion of Results: It is of prime interest to compare the results of experiment with the theory of Kemble and also that of Reiche. Using Eq. 3, we have computed the positions of the maxima of the envelop of the absorption bands for the temperatures 200° K and 291° K. In computing the values we have made use of the relations that $f = f_0 \pm f_r$. Where f_0 is the frequency of vibration of the molecule and corresponds to a wave length $\lambda = 3.463\mu$ and f_r are the frequencies computed from Eq. 3. The values $R/N = 1.372 \times 10^{-16}$, $h = 6.545 \times 10^{-27}$, and $J = 2.7 \times 10^{-40}$ were used. The results are embodied in the following table.

	T	Setting (left)	λ (left)	Setting (right)	λ (right)
By Eq. 3	291°K	18.50	3.3897 μ	19.31	3.5395 μ
By experiment	291°K	18.53	3.397	19.30	3.538
By Eq. 3	200°K	18.56	3.4021	19.23	3.5262
By experiment	200°K	18.65	3.419	19.17	3.514

For the temperature 291° K there is a fairly good agreement between theory and experiment. For 200° K there is a divergence indicating perhaps that Eq. 3 may need modification for the low temperatures. It is to be noted, however, that it is difficult on account of the nature of the envelop of the absorption bands to locate with a high degree of accuracy the points of maximum absorption. The deviation in the case of the low temperature may be due to error in locating the maxima.

By the use of Eq. 4, we find in the same manner as Reiche (loc. cit.) that the position of the bands of maximum absorption for 291° K should be the third on each side of the centre. For 200° K, Eq. 4, locates the position of the maxima at the second band on each side of the centre, a result in accord with experiment.

We are indebted to the Rumford Committee of the American Academy of Arts and Sciences for aid in carrying out the investigation, and take this occasion to express our appreciation.

NORTHWESTERN UNIVERSITY,
EVANSTON, ILLINOIS

Spherical Aberration in Thin Lenses.—A paper by T. Townsend Smith presents an elementary theory of the spherical aberration of thin lenses, to give means for determining quickly the aberration of any thin lens for any position of the object, and to formulate a statement of the conditions under which the spherical aberrations of two thin lenses will compensate one another. This last is confined to the simplest case, in which the lenses are close together. The treatment is in part analytical, in part graphical.

In addition, there is included in this paper a graphical solution of the problem as to the conditions under which a two-piece lens may be achromatic, free from axial spherical aberration, cemented, and free from coma, and the shapes of the lenses necessary to satisfy these different conditions are shown. The effect of a slight change in the shape of the lenses is also indicated.

It is not expected that any of the material is really new, but the author knows of no place where the information given may be readily obtained, even piecemeal. (Bureau of Standards Sci. Paper No. 461.)

Some Optical and Photoelectrical Properties of Molybdenite.—A paper published by W. W. Coblentz and H. Kahler gives new data on the transmissivity and the reflectivity of molybdenite; also data upon its change in electrical conductivity, when exposed to thermal radiations of wave-lengths extending from the ultra-violet into the extreme infrared. The effect of temperature, humidity, intensity of the exciting light, etc., upon the photoelectrical sensitivity of molybdenite was also determined.

It was found that:

(1) Samples of molybdenite, obtained from various localities differ greatly in sensitivity.

(2) There are maxima of sensitivity in the region of 0.73μ, $.85\mu$, 1.02μ, and 1.8μ.

(3) There is no simple law governing the variation in the photoelectric response with variation in intensity of the radiation stimulus.

(4) The increase in photoelectric current with increase in intensity of the incident radiation is greatest for infrared rays. It is greatest for low intensities of the exciting light and it is greatest on the long wave-length side of the maximum.

(5) The photoelectric sensitivity increases with decrease in temperature. At 70° C the bands at 1.02μ and 1.8μ have practically disappeared. On the other hand, at liquid air temperatures, the greatest change in electrical conductivity is produced by radiations of wave-lengths between 0.8μ and 0.9μ.

Unlike selenium, molybdenite appears unique in being photoelectrically sensitive to infrared rays, extending to about 3μ. (Bureau of Standards, Sci. Paper No. 398.)

INSTRUMENT SECTION

APPARATUS FOR ADMITTING GAS INTO A VACUUM

By J. B. Johnson and H. W. Weinhart

In experiments dealing with gases at low pressures it is often desired to repeatedly admit small measured quantities of gas into an evacuated system without appreciably reducing the purity of the gas and without waste of gas from the container. The apparatus to be described here has been used for this purpose with considerable success in this laboratory and may be of interest to others confronted with similar problems.

The apparatus is in principle an inverted Topler pump, in that a small volume of gas from a gas container is trapped between mercury columns in a capillary tube and carried into the low pressure apparatus. A diagram of the construction is shown in the figure. The apparatus is made of $\frac{3}{8}''$ diameter glass tubing with the exception of the capillary tube C which has a bore of about one millimeter and which extends into the enlargement E in the tube A. The mercury is contained in the two reservoirs R_1 and R_2 which are connected to the glass by thick rubber tubes. The tube A is connected to the gas container G through the small trap T, while tube P leads to the vacuum pump and to the evacuated apparatus into which the gas is to be admitted.

The total height of the apparatus is somewhat greater than twice the height of the barometric mercury column at atmospheric pressure, so that with ordinary care there is no danger of losing the gas or letting air into it when the pressure on the pump side of the system is changed. The apparatus is mounted on a board in such a way that all the parts can be heated with a bunsen flame during evacuation.

The transfer of gas from the high pressure side to the vacuum side of the system is made by forcing a column of gas of predetermined length through the capillary tube C into the tube D. The length of the column of gas to be transferred is fixed by the adjustment of the mercury reservoir R_2 so that the mercury column in the capillary stands at the desired distance from the top of the tube. The reservoir R_1 is now raised until mercury from the tube B fills the enlargement E and flows down through the capillary, carrying the gas column with it into the larger tube D where the bubble rises through the mercury

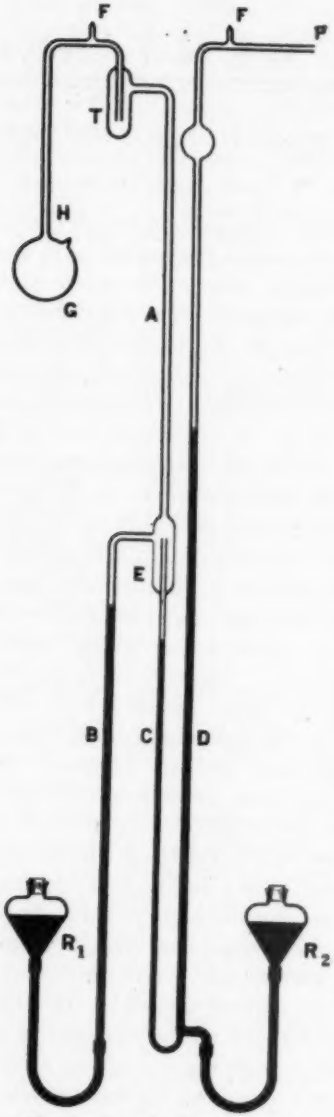

FIG. 1. *Gas admitting apparatus.*

into the evacuated system. If it is necessary to exclude mercury vapor from the attached apparatus, a trap cooled in liquid air may be inserted in the tube *P*.

In this way a column of gas as short as one centimeter can be transferred without sticking at the junction of the capillary and the wider tube, while the longest column of gas that can be carried over is nearly as long as the capillary tube *C*. For the purpose of estimating the pressure change which can be produced in the low pressure side by one stroke of the mercury piston, we may assume that the pressure in the gas reservoir is one-half atmosphere and the volume of the evacuated apparatus is 1000cc. The range of pressure change which can be produced with one stroke is then between .003 mm and .25 mm assuming the capillary to have one millimeter bore.

The method of attaching the gas reservoir without contamination of the gas requires a brief description. The gas container is a glass bulb of the kind in which the rarer gases are now commercially obtainable, which can be opened by breaking an internal seal at *H* in the connecting tube by a falling steel ball. Before the gas is released from the bulb, the two sides of the system are connected together by a small glass tube sealed on at *F-F*, and the system is connected to the vacuum pump at *P*. During evacuation the whole system, including the mercury columns, is carefully but thoroughly heated with a bunsen flame until a satisfactory vacuum is obtained. The small connecting tube is then sealed off and after the glass has cooled down the gas is released from the bulb by breaking the internal seal. The small pieces of broken glass which might otherwise get into the capillary tube are caught in the trap *T*. The gas can now be kept indefinitely and is always available in its original state of purity.

RESEARCH LABORATORIES OF THE
AMERICAN TELEPHONE AND TELEGRAPH COMPANY, AND THE
WESTERN ELECTRIC COMPANY, INCORPORATED.
NOVEMBER 18, 1922.

Spectrophotoelectrical Sensitivity of Some Halide Salts of Thallium, Lead, and Silver.—W. W. Coblentz and J. F. Eckford have completed the study of the effect of crystal structure, chemical constitution, and atomic weight upon spectrophotoelectrical sensitivity. It is shown that these three factors have a definite effect upon the photoelectrical reaction just as previously they were found to have a specific effect upon absorption and reflection spectra.

It was found that the spectrophotoelectrical reaction of the halide salts of thallium, lead, and silver is confined to a very narrow region of the violet end of the spectrum, being the narrowest and most sharply defined reaction spectra of all substances yet published, including the photoelectric gas-ionic reaction spectra of the alkali metals.

Data are given showing that increasing the atomic weight of the acid element in the salts of thallium shifts the maximum of the spectrophotoelectrical reaction towards the long wave lengths. The maximum of the spectrophotoelectrical sensitivity of TlCl is at 0.365μ; of TlBr at 0.413μ; and of TlI at 0.455μ.

The photoelectrical sensitivity curves of the halide salts of thallium have the outline of what appears to be the typical spectrophotoelectrical reaction curve, viz, a high photoelectrical reaction on the short wave length side of the maximum, and a very abrupt termination of the reaction on the long wave length side of the maximum.

Lowering the temperature of TlI to $-60°$C. had no appreciable effect upon the position of the maximum of the spectrophotoelectrical reaction.

Of the halide salts of lead, $PbCl_2$, $PbBr_2$, and PbI_2, only the iodide was found to react photoelectrically. The spectrophotoelectrical sensitivity curve of lead iodide appears to be complex with an ill-defined maximum in the region of 0.45μ, and sharply-defined maximum at 0.52μ.

The halide salts of silver appear to be sensitive photoelectrically when melted into a vitreous or semi-vitreous mass. Silver chloride exhibited photoelectrical sensitivity in the region of 0.38μ. Silver bromide has a maximum at 0.46μ. The sensitivity curve of silver iodide appears to be wide and complex with maxima at about 0.47μ and 0.50μ respectively.

In connection with these silver halide salts, an examination of samples of silver nitrate and potassium nitrate showed no photoelectrical sensitivity. (Bureau of Standards, Sci. Paper No. 456.)

AN IMPROVED METHOD FOR THE CONTROL OF TEMPERATURE AND OTHER PHYSICAL QUANTITIES

By Paul E. Klopsteg and W. H. Stannard

The automatic control of such physical quantities as temperature, pressure, humidity and the like, particularly the kind of control whereby it is desired to maintain such quantities at constant value, constitutes an everyday laboratory problem. As the allowable limits of variation are reduced the difficulty of automatically holding the values within the desired limits becomes immensely greater.

One of the most common laboratory requirements is for a constant temperature bath. One investigator may desire a bath which, over an interval of several hours, will show a maximum temperature change, at any particular point within the bath, of a few thousandths of a degree. Another may desire this degree of constancy and the same degree of uniformity throughout the bath during intervals of a few hours. A third may be satisfied with constancy within a few hundredths of a degree of average temperature but may wish to have the average temperature remain the same for days or weeks continuously, and he may be willing to go to some pains in looking after the maintenance of the control mechanism to secure the desired end. A fourth investigator (and he is in the majority) may desire the same results as the third but minus the pains of maintenance.

This paper describes a mechanism for holding constant within narrow limits such physical quantities as those first mentioned for the fourth member of the above hypothetical group. The development of the device was made with the object of securing close regulation of the temperature in an oil bath. One of the requirements was that there should be very little drift of the average regulating temperature over periods of days or weeks at a time. So far as we know the method is new[1] and its application to the control of different physical quantities should materially increase the reliability of such control.

Referring specifically to temperature control, our problem was to keep as small as possible the variation of temperature in a bath of oil, at any point between room temperature and 100°, or somewhat higher.

[1] Patent application has been made.

The permissible limits to the variation were $\pm .14°$. An additional requirement was reliable performance within these limits under "industrial laboratory conditions." The latter we interpreted as meaning plenty of dirt, little attention to an operating mechanism so long as it seems to be operating, large variation of room temperature, and sudden large changes in line voltage. Bearing these various points in mind, we ruled out the mercury thermoregulator because of maintenance requirements and because a relay is needed, which adds to the number of parts likely to give trouble.

This left available some type of regulator with solid electrical contacts, motion of one of which is produced by temperature changes in a strip or helix of "thermostatic metal." The latter consists of two laminae of brass and invar, respectively, welded together. In a regulator of this type, the pressure between the electrical contacts at the desired temperature is nil, with probable high resistance; consequently there must be a further temperature drop to produce sufficient pressure to allow the full heating current to flow. Again, there is inevitably occasional sticking at such contacts, making necessary a change of temperature in the opposite direction, beyond the desired point of regulation, to separate the contacts. The variations so produced may not be large, but there is always the possibility of an occasional large change due to dirt between or sticking of the contacts.

It was thought that the difficulty of imperfect contact on closing, and of sticking on opening, might be considerably reduced by causing the contact surface of the "fixed" contact to move, without changing the separation between the two contacts. This can be accomplished in several ways, the simplest being to prepare a true cylinder of the contact material—in our experiments silver—and cause this to revolve on its own axis, contact being made on the cylindrical surface. This had the desired effect, but manifested an unexpected and undesirable characteristic. The sensitivity[2] of the regulator was only 2/7 as great as when the "fixed" contact had a stationary surface. The reason for this result is the unavoidable roughness of the moving surface, combined with the small controlling force and vibrations of the apparatus. These require that there be considerable pressure between the contacts in order to maintain a circuit of definite resistance value. With small contact pressures, the current is intermittent, and its average value is

[2] This may be taken as an inverse function of the temperature change required to change the contacts from definitely open to definitely closed, and vice versa.

considerably less than the maximum. The average value of this intermittent current, due to rapid opening and closing of the contacts, probably brought about by vibration of the mechanism, varies with temperature changes and thus is effective in controlling the temperature, so that, with clean contact surfaces, the closeness of control during short intervals is greater than the sensitivity ratio above mentioned would indicate. There is, however, persistent arcing at the contracts, leading to rapid erosion and consequent drift in the bath temperature.

The next step in the development was to improve the sensitivity and prevent erosion due to arcing, at the same time retaining the advantages of the rotating contact. The outcome was a regulator in which the thermally sensitive element retains complete control of the situation, but in which we have secured great sensitivity, no sticking, and elimination of arcing at the control contacts. In applying this regulator to the bath, we took great care in providing for rapid circulation of the bath liquid and in using heaters with the smallest possible lag. Both are essential to close regulation and to uniformity of temperature throughout the bath.

Fig. 1 illustrates in a schematic way the method adopted for accomplishing the purpose. The line voltage E is applied to the heating unit H_1, through the regulator R, and the rotating interrupter A. H_2 is an additional heater which can be permanently switched on. The regulator R is composed of a helix of invar-brass laminated metal, temperature changes in which cause the arm L to swing through an angle corresponding to the temperature change. At the free end of L is a contact C_1 and an iron armature F; C_2 is the fixed contact, which may have a moving contact surface, as previously mentioned. The fixed contact is carried on an electromagnet M, the current through whose winding must enter at C_2. The interrupter A consists of a cylinder of metal with an insulating segment N, which, in its rotation, periodically opens the circuit at the brush b. K is a condenser or other device for reducing the amount of arcing at the interrupter.

The operation is as follows: With the thermosensitive helix in the bath liquid (oil), cooling of the latter will cause the contact C_1 to close on C_2. Current through the heater H_1 will also energize the magnet M, causing a pull on armature F, thus insuring firm contact, and minimum contact resistance. The current persists until the interrupter breaks the circuit when the insulating segment N reaches the contact brush b. If the heat input has been sufficient, and the lag sufficiently

small, contact C_1 will then move away from C_2. Contact will again be made when the regulator has responded sufficiently to the cooling of the bath liquid.

The advantages of this arrangement, especially when the "fixed" contact is of the rotating type, are enumerated below. They are illustrated in the performance data given later.

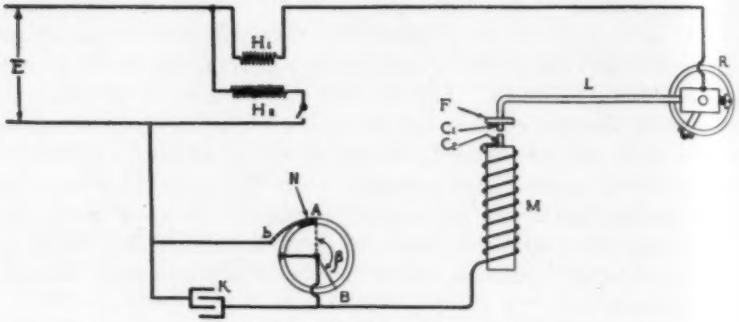

FIG. 1. *Schematic diagram of connections.*

1) The heating current is never broken at the control contacts, but always at the interrupter. This makes for long wear and consequent reliability, since the greatest—we might say almost the sole—cause of disintegration of the contact is removed.

2) Since the destructive arcing is eliminated, there is no "welding" and hence no sticking; sticking is also prevented by the relative motion between the thermally controlled contacts.

3) The electromagnetic means for producing definite pressure between contacts the instant the circuit is closed results in a firm "wiping" contact action, which makes the arrangement self-cleaning.

4) The contact pressure results in "vigorous" control; the heating current is on or off with certainty, but is entirely subject to the action of the thermally sensitive element.

5) Pressure between the thermally controlled contacts, together with elimination of the interruption of the heating current at this point, makes possible a very high rate of energy input. This is especially desirable in cases where cool objects are introduced into the bath, or where the bath is subjected to large fluctuations in room temperature, since it insures very rapid return to the temperature of regulation.

6) When the rate of interruption[3] is properly chosen, and all parts of the control mechanism properly co-ordinated, the mean temperature of the bath is singularly independent of fluctuations in line voltage and room temperature.

One possible disadvantage of this type of controlling mechanism is the necessity for operating the interrupter by some auxiliary means, but since it is necessary in any case to stir the bath, it is always possible to utilize the stirring motor for driving the interrupter. The interrupter may, of course, be located at a point distant from the regulator, and other methods for producing periodic interruptions can be employed. An automatic sign-flasher is an example.

The sketch shown in Fig. 2, together with the reproductions of photo-

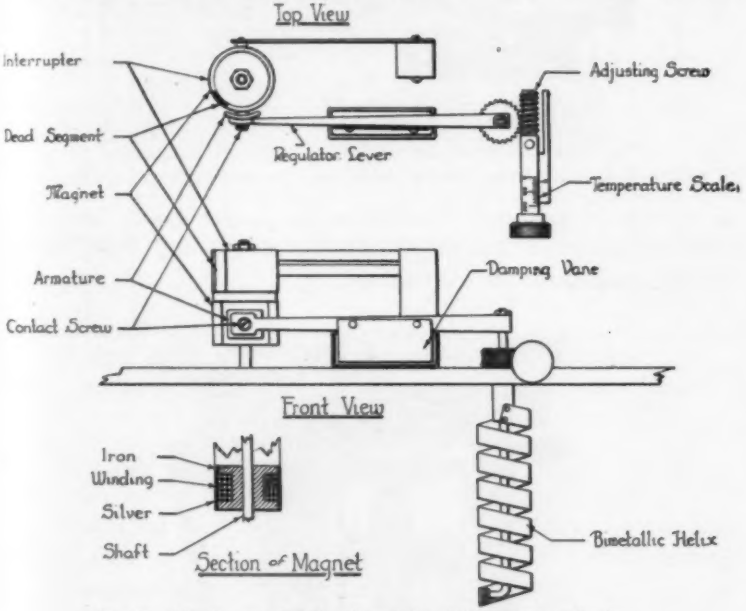

FIG. 2. *Showing construction of control and interrupter mechanism.*

[3] The interval between interruptions should not be greater than half the lag of the bath, and preferably less, the lower limit depending only upon the proper functioning of the mechanism. By "lag" of the bath we mean the interval between the instant when the bath as a whole has a certain average temperature and the instant when the regulator assumes the setting corresponding to this condition. This involves the speed with which the heaters can transfer their heat energy to the bath liquid, the rate of circulation and thoroughness of stirring, and the speed with which the regulator responds to the temperature of the liquid flowing over its sensitive element.

graphs, Fig. 3 and Fig. 4, depict one successful design embodying the ideas outlined above. The electromagnet was mounted within a silver cylinder on the same shaft with the interrupter, its axis in the axis of rotation, and its flanges iron. With this arrangement a definite grip

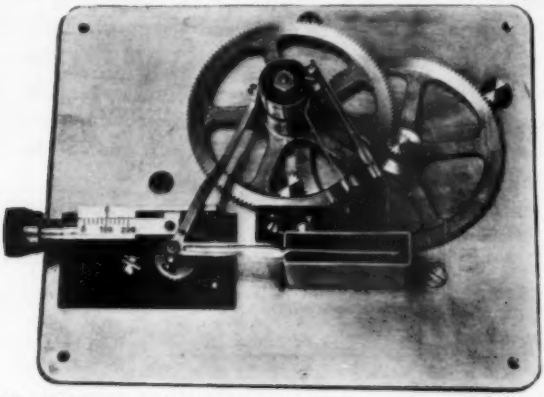

FIG. 3. *Showing one practical form of control apparatus embodying the method described.*

on the contact is assured, regardless of the instant during the cycle at which contact occurs, and the advantage of the rotating "fixed" contact —a self-cleaning surface—is retained.

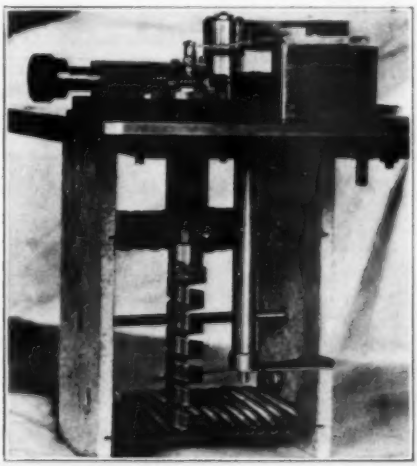

FIG. 4. *Showing one practical form of control apparatus embodying the method described.*

The unit just mentioned was used in connection with an oil bath of 5 liters capacity, using liquid petrolatum as a bath medium, and operated at about 100°C. During a period of ten consecutive days (excepting one Sunday), in which the apparatus received no attention whatever, running eight hours a day, the temperature remained within .05° of average value, and with few exceptions within .03°. Fig. 5 shows the manner in which the bath recovers its temperature of regulation as compared with the manner of recovery of a bath (Fig. 6) in

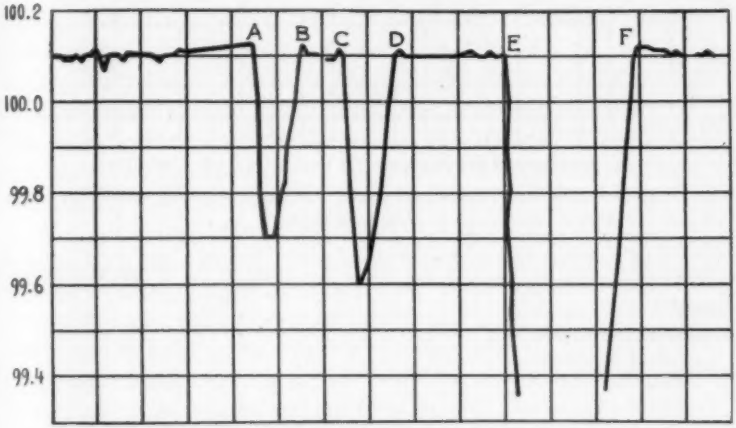

FIG. 5. *Recovery of bath temperature with improved method of control. Sudden cooling at A, C and E.*

the regulator of which the electromagnetic grip is omitted. The reason for the different behaviors has been mentioned earlier in this paper.

Apparatus has been devised but not yet tested, in which the plan of securing contact pressure at the regulating point and of eliminating the interruption of the control current by the automatically operated contacts, has been incorporated in automatic devices for holding constant such physical quantities as pressure, liquid level, and rate of flow. The same system of control can also be applied to a mercury thermoregulator, but experiments along this line have been deferred, pending the results of other development work now under way. The electromagnetic grip and interrupter arrangement is also applicable to "program" or "schedule" control, in which the quantity being

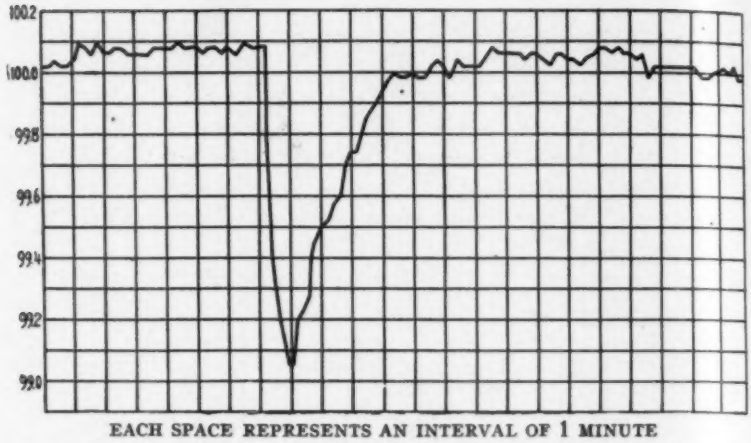

FIG. 6. *Recovery of bath temperature after cooling, regulator with moving contacts but without electromagnetic grip.*

controlled may be caused to vary accurately in a predetermined manner.

DEVELOPMENT LABORATORY,
CENTRAL SCIENTIFIC CO.,
CHICAGO, ILL.

THE REGISTERING MICROPHOTOMETER OF THE MOUNT WILSON OBSERVATORY

By Edison Pettit and Seth B. Nicholson

The purpose of the registering microphotometer (Fig. 1) is to register electrically the variations in density across a photographic image. As originally designed by Babcock, the photoelectric cell was employed as the sensitive element. We have substituted the vacuum thermopile on account of its simplicity and easier control.

The instrument consists principally of four parts: the microscope with moving stage and thermopile *P*, which constitutes the photometer; the gear box and multiplier *G G;* the photographic registering device *H;* and the galvanometer and lamp *O U*. The entire apparatus rests on a cast iron bed-plate *A B*, 12 feet long by 28 inches wide.

The microscope stage *E* is driven by a screw *Z*, which is connected through the gear box and multiplier *G G* with the screw *S* which drives the photographic registering device *H*. By means of the gear box and multiplier the registering apparatus may be driven at a speed from 2 to 500 times as great as that of the microscope stage *E*. Power to drive the apparatus is derived from the motor-driven cone-wheel *M*, which moves the plate *D* at speeds varying from ½ to 2 inches per minute. By means of the motor *N* the plate may be returned to the starting position at a speed of 3 feet per minute. Curves which are to be compared can thus be registered in the same direction, which eliminates the galvanometer lag.

The registering device *H* consists of a plate-carrier containing the plate *D* which is driven slowly past the cylindrical convex lens *L* of 1 cm aperture and 15 cm length. Light from the straight-filament lamp *U* falls on the mirror *R*, which returns it to the galvanometer mirror. The light again returns to *R* and is reflected to the reversing mirrors *X*, which cause an image of the filament to play up and down the lens *L*. Thus, as the plate *D* passes *L*, a curve is formed photographically which represents the variations in the current through the galvanometer.

The galvanometer is connected with the thermopile *T*, placed directly above the microscope of the photometer *P*. Both artificial and solar illumination have been used, the instrument being shown arranged for

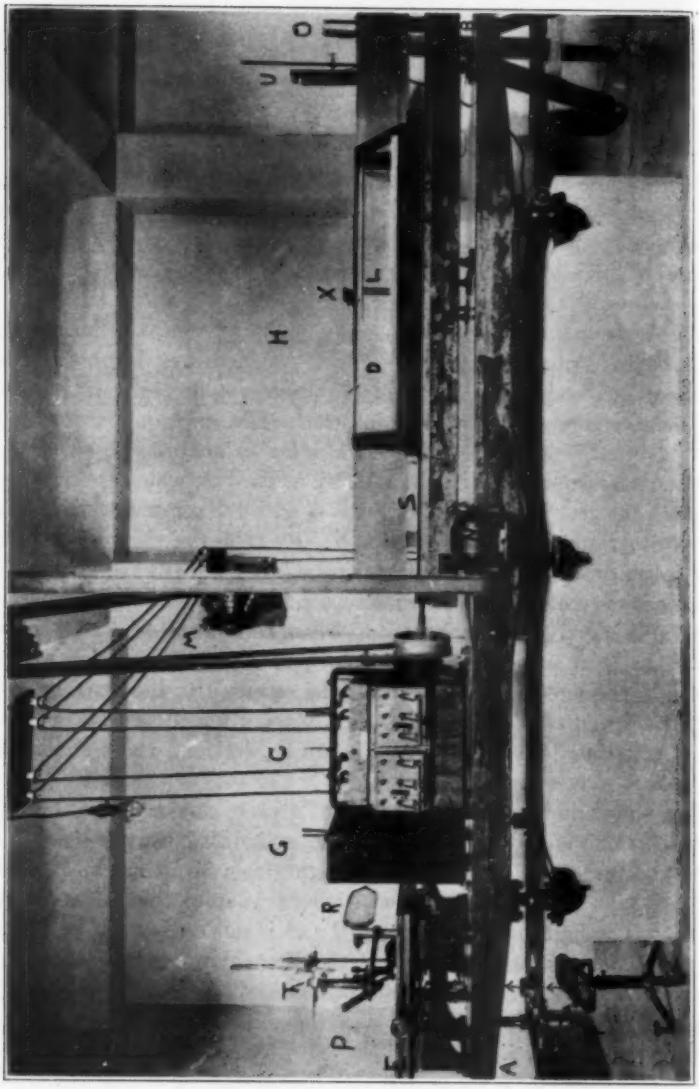

FIG. 1. *General view of the registering microphotometer.*

the latter. The dotted lines show the path followed by the beam of light operating the photometer.

Fig. 2 shows the photometer in detail, the dotted line indicating the path of the beam of sunlight operating the apparatus. The negative whose density gradient is to be examined, a spectrogram, let us say,

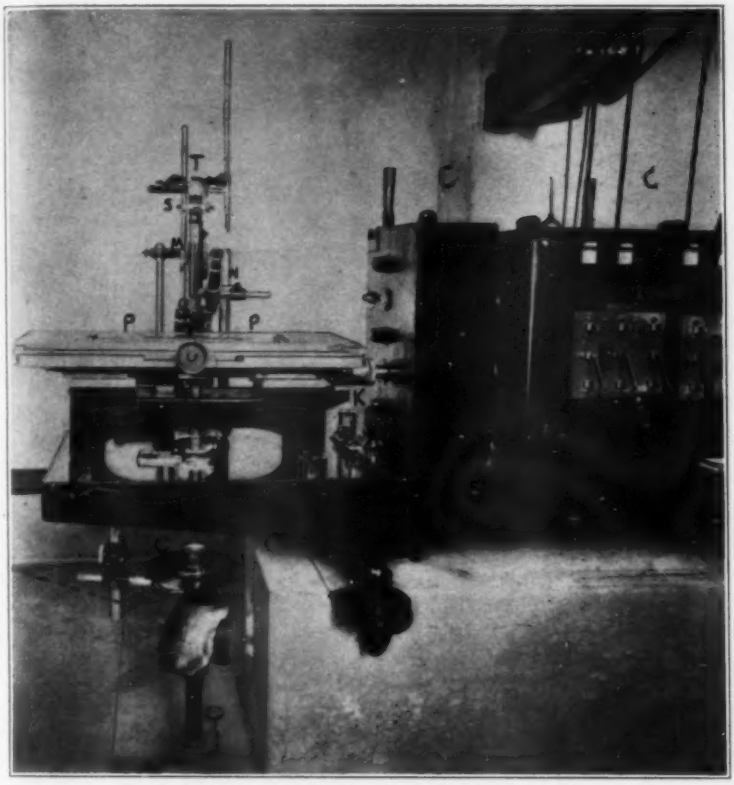

FIG. 2. *Detail view of the photometer.*

is placed on the moving microscope stage at *P P*. Sunlight passing through the condensing lens *C* is brought to a focus on the collimator slit S_1, where an image of the sun is formed. An image of this brilliantly illuminated slit is projected on the film of the negative *P P* at *L*. The microscope objective O_2 focuses an image of this illuminated

region of the negative upon a second slit S, just below the vacuum thermopile T. The operation of the registering microphotometer is then as follows: The gear box and multiplier $G\,G$ having been set for some ratio, say 100, the motor-drive is started, which causes the negative $P\,P$ to move slowly beneath the microscope; at the same time the photographic plate in the registering device is driven past the cylindrical lens with a speed 100 times as great. The variations in the intensity of the beam transmitted by the negative at L are transmitted to the thermopile T cause the galvanometer beam to play up and down the cylindrical lens, thus producing a curve on the moving plate which represents the density gradient in the negative $P\,P$ on a scale 100 times as great as in the original.

FIG. 3.

It is obvious that the accuracy with which the photometer registers the density curve of a negative depends on the width of the slit S, just below the thermopile T. The narrower the slit, the more accurately will the curve represent the density gradient. If, however, the slit is too narrow, the irregularities in grain structure and defects in the film will produce false depressions and elevations in the curve. For certain problems, the study of energy relations across spectral lines for example, we may use a narrower slit, if its length is correspondingly increased. It will then be necessary to employ a device to bring the entire image upon the thermopile.

Fig. 3 shows how this is done. Here S_1 is the brilliantly illuminated collimator slit, and L is the image of this slit cast by the lens O_1 on the film surface of the negative being investigated. M_1, M_2 are two parallel plane mirrors placed in the microscope barrel, which compress the image of the slit L longitudinally upon the second slit S, so that all the light proceeding from L shall fall on the thermopile. The full lines indicate the path of the rays in the new arrangement and the dotted lines the path without the mirrors. It is thus possible to integrate over a line at L three times as long as with the old arrangement, and hence

FIG. 4. *Intensity curve across the H and K lines in the spectrum of integrated sunlight. Original spectrum is shown above on the same relative scale.*

to use a slit S of only one-third the width formerly used, thus gaining in the effective resolving power without increasing the errors due to defects and grain in the film.

Fig. 4 is a curve taken across the H and K region of the solar spectrum. The original spectrogram, shown above on the same scale, was made with a 13-foot grating spectrograph in the first order, 15 000 lines to the inch. A speed ratio of 1 to 10 was used between the photometer and register, so that the lines are here separated by 10 times the original amount. Since the original was a negative, the lines are represented by depressions in the curve.

Fig. 5 shows the same spectral region photographed near the limb of the sun, where slight reversals are seen in the H and K lines. Two

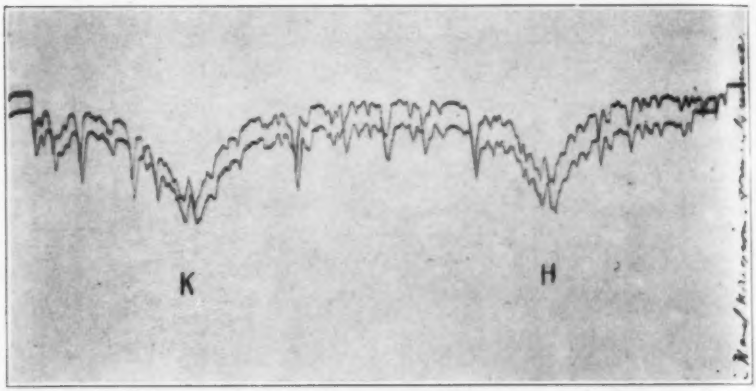

FIG. 5. *Duplicate intensity curves across H and K lines in spectrum of the sun's limb.*

runs were made, forward and back; the resulting slight horizontal displacement between the two curves is due to the galvanometer period. Note the agreement between the two curves.

Fig. 6 shows the same region of the spectrum observed in the chromosphere of the sun. The strong reversals in H and K will be noted. The reversal in H is not quite so symmetrical as that in K. This has a bearing on thei nterpretation of spectroheliographic results.

Fig. 7 shows the head of the carbon band λ 3890 in the solar spectrum with the carbon arc spectrum of the same band in comparison. The original spectrogram is shown on the same scale at the top of the figure.

A gear ratio of 1 to 50 was used to obtain this curve. In the original spectrogram shown above are two exposures on the arc spectrum with solar spectrum between taken in the 5th order of the 30 foot grating

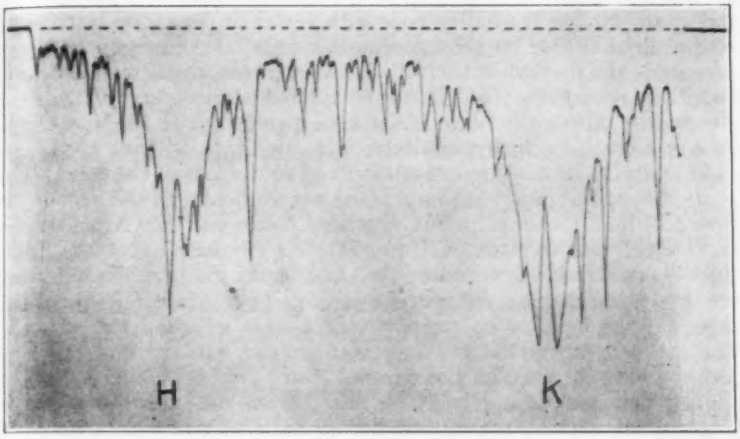

FIG. 6. *Intensity curve across the H and K lines in the spectrum of the chromosphere o the sun, showing the reversals of these lines.*

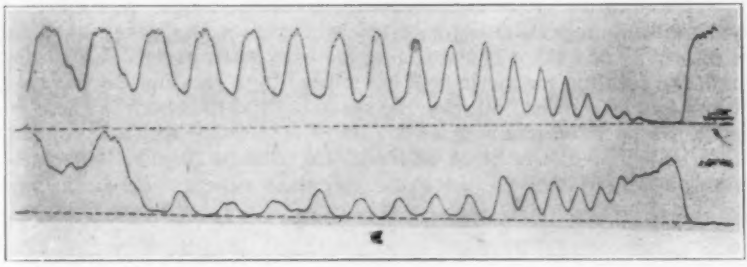

FIG. 7. *Intensity curve across the head of the λ3890 Carbon band (below) and the same region in the solar spectrum (above). The original spectrogram is shown at the top of the figure.*

spectrograph, 15 000 lines to the inch. Below is shown the curve across the solar spectrum, and below that, the corresponding curve across the arc spectrum.

MOUNT WILSON OBSERVATORY,
OCTOBER, 1922.

A New Method of Measuring e/m.—The electron-beam from the cathode of a Braun tube is subjected to a rotating (three-phase) magnetic field, the force-lines of which run perpendicular to the axis of the tube. The beam is thus deflected in all azimuths successively, so that the portion which passes through the anode diaphragm describes the surface of a hollow cone with vertex at the anode hole, and a ring of light is seen on the fluorescent screen. A long cylindrical coil surrounds the portion of the tube between anode and screen so that a longitudinal magnetic field H can be applied to the beam. If w is the component of velocity of an electron perpendicular to the axis of the tube, a force Hew, with e in electromagnetic units, will act upon it at right angles to its direction of motion and to the axis of the tube. The projection of its spiral path on a plane perpendicular to the axis of the tube will be a circle, of radius, r, where $Hew = mw^2/r$. After a time $t = 2\pi m/eH$ the electron will arrive again on the axis of the tube. But $t = 2\pi m/eH$ and is therefore the same for all the electrons. During the time t, the electron will travel a distance $l = tv = 2\pi mv/eH$ along the tube. If the longitudinal magnetic field is so adjusted that l is the distance between anode and fluorescent screen, a sharp image of the diaphragm is obtained on the screen. Now $\frac{1}{2}mv^2 = Ve$, where V is the applied potential, and H may be found from the dimensions of the longitudinal coil and the current flowing in it. Taking the field H to be uniform, the final formula is

$$\frac{e}{m} = \frac{8\pi^2 V}{H^2 l^2}.$$

A representative set of measurements gave the value $e/m_0 = 1.768 \cdot 10^7$ with maximum possible error of 1%, where m_0 is the rest-mass of the electron. The author is continuing his work with improved facilities; e.g., the rotating magnetic field is replaced by a rotating electric field, which can be screened off from the space beyond the anode. There are good prospects of attaining an accuracy of 1/10%, which is comparable with that of any other method. [H. Busch, Physik. Zeitschrift, *23*, pp. 438-440; 1922.]

ARTHUR E. RUARK

A CONTINUOUSLY VARIABLE RHEOSTAT WITH CONSTANT CONTACTS

By Paul Kirkpatrick

In investigations employing a Coolidge x-ray tube much difficulty was experienced in securing a means of filament current control capable of fine, continuous adjustment and free from fluctuation. The current was supplied from a twelve volt storage battery and rheostats of several types were included in its circuit at different times. The requirements were good carrying capacity combined with precise and duplicable variability through a range of a small fraction of an ohm. Ordinary spool rheostats with sliding contacts were unsuited by reason of not permitting a truly continuous variation of resistance. Straight slide-wire rheostats free from this feature were tried but it was found that the resistance at the contact between wire and slider varied uncontrollably as the settings were altered, causing minute changes in the filament current and hence highly amplified fluctuations in the tube milliamperage. Vertical resistance wires dipping in tubes of mercury were found when withdrawn from the tubes to carry up mercury which later ran down or dropped off, changing the resistance of the system and therefore the strength of the tube current in a freakish and intolerable way.

The type of rheostat here described was finally adopted and it has proved to be a complete solution of the difficulties. Its chief feature is that of allowing a perfectly continuous resistance variation without any sliding or otherwise changing contracts. In principle this depends upon the alteration of the length of the resistor (mercury) by extending it in the middle, the end conditions being unchanged.

A vertical tubular mercury well (*A*) accommodated a glass tube (*B*) of slightly smaller diameter arranged to be raised or lowered by a counterbalanced cord. A metal rod (*C*), its upper end fixed at some height above the well, enters the central tube and dips to a small distance in the mercury. The upper end of this rod forms one of the terminals of the rheostat; the other terminal consists of a wire dipping into the well at one side. The length of the mercury path is increased or diminished by lowering or raising *B*. The resistance range of the instrument depends of course upon the dimensions of the tubes; the

proper values for a desired range are readily computed. Iron is preferable to copper for the terminals as the latter metal amalgamates with mercury.

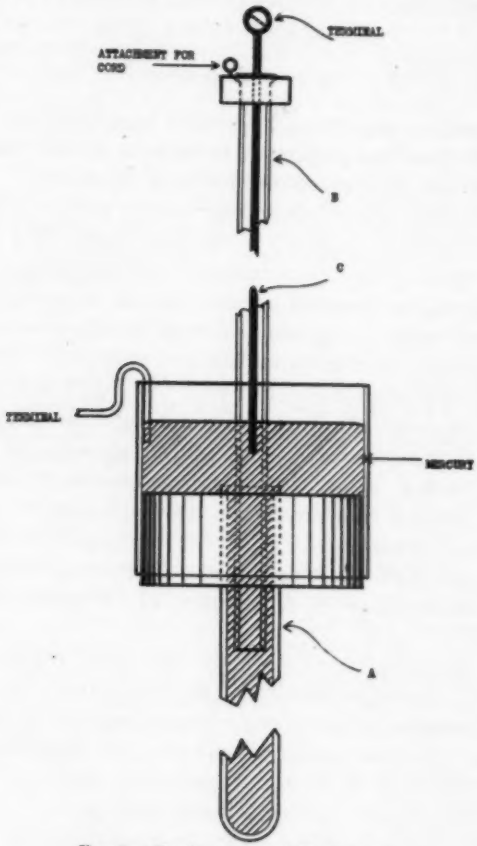

FIG. 1. *Continuously variable rheostat.*

In the rheostat pictured the tube *A* has a length of 60 cm and an external diameter of 9 mm. The external diameter of *B* is 6 mm. Its maximum resistance is about one tenth of an ohm. In use it carries a current of about three amperes without warming appreciably. A ten step rheostat is used in series for fixing the general magnitude of the current desired.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF CALIFORNIA.

THE PRACTICAL APPLICATION OF PARABOLIC SURFACES IN LENS CONSTRUCTION

By W. B. Rayton

Since the days of Kepler, the computation of non-spherical surfaces which would eliminate one or more of the aberrations due to spherical surfaces has fascinated the theoretical optician. For the most part, he has had to rest content with the contemplation of the excellence of the correction or the simplicity of the construction which would result if it were only possible to produce in manufacture the surfaces he would prescribe.

In general these surfaces cannot be expressed by any simple mathematical equation but there are cases, well known to this society, in which the solution of the problem leads to surfaces of elliptical, hyperbolic, or parabolic cross section. Two notable examples are reflecting telescope objective mirrors and search light mirrors, wherein parabolic surfaces give perfect correction of spherical aberration for all zones. Telescope mirrors with parabolic surfaces of a high degree of excellence are produced by empirical methods. The generation of parabolic surfaces on search light mirrors is accomplished by machinery but no machinery has thus far come into practical use which can generate the non-spherical surfaces to which computations usually lead.

We have found that the osculating paraboloids are, in general, much closer approximations to the required aspheric surfaces than are the osculating spherical surfaces and that, furthermore, a suitable choice of the spherical surface or surfaces combined with it leads to an aspheric surface which is a remarkably close approximation to its osculating paraboloid. By the combination of spherical and parabolic surfaces we are therefore enabled to achieve results in the correction of aberrations which are absolutely impossible with spherical surfaces alone.

For several years the Bausch & Lomb Optical Company has been using such surfaces in the manufacture of aplanatic substage condensers of high numerical aperture for the microscope and in condensers for photomicrography. They permit a very excellent correction of spherical aberration and constitute an immense improvement over spherical

surfaces even when the figure of the parabolic surfaces is far from perfect.

With increasing experience, we developed more and more accurate methods and machinery until we felt justified in extending the application of such surfaces to larger lenses and to lenses requiring very accurate surface figure. Our success in this direction is thought worthy of the attention of this society.

One of the first problems attacked was the elimination of the astigmatism of oblique pencils in spectacle lenses of high plus power. Spherical curves do not permit reduction of this astigmatism to amounts desirably small when the power of the lens exceeds about 8.00*D*. The higher powers have been corrected heretofore with aspheric surfaces which are extremely expensive to produce even of sufficient accuracy for spectacle lenses whose surfaces do not require the degree of accuracy common to photographic or telescope objectives. We find, however, that we can get a very excellent degree of correction in a cheaper lens by the employment of one spherical and one parabolic surface. Astigmatism can be absolutely corrected for one zone and the residual zonal errors are very small—less serious in their effect upon vision than the chromatic difference of magnification present.

Fig. 1 shows a +12.00 *D* spectacle lens of the most favorable form made with spherical surfaces. The curve at the right shows the

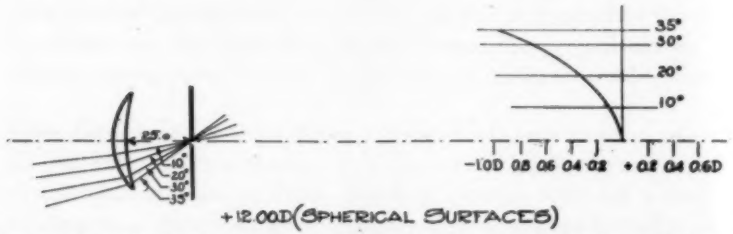

FIG. 1. *Curve showing the astigmatism in the case of a + 12.00 D spectacle lens with spherical surfaces.*

difference in power between the tangential and sagittal sections for angles of view up to 35° from the axis of the lens in the image space. Fig. 2 shows a lens of the same power whose front surface is parabolic. The curve at the right, again, shows the state of the astigmatic correction. The astigmatism is corrected for an angle of about 27° and the residual error for other angles reaches, at its maximum, 0.08 *D*. The improvement over the lens with spherical curves is remarkable.

Another very promising field presented itself in the case of condenser lenses for motion picture projection where the high magnifications and long projection distances make it impossible to get sufficient and uniform illumination without very high consumption of electric current.

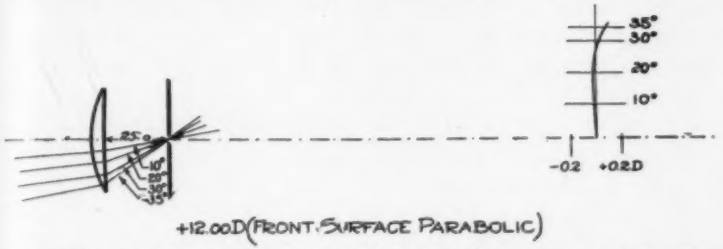

FIG. 2. *Curve showing astigmatism of a +12.00 D spectacle lens with one surface parabolic.*

In the employment of condensers of the ordinary sort with spherical surfaces there has been a substantial loss of light due to spherical aberration in the beam of light issuing from the condenser. The result of the spherical aberration is an uneven distribution of light within the cone and uneven illumination of a screen placed at right angles to the axis of the zone so that, in the effort to get passably even illumination of the projected picture, the diameter of the spot of light at the film gate has to be made much larger than would be necessary if the distribution of light within the cone were uniform.

PROJECTION CONDENSER(SPHERICAL SURFACES)

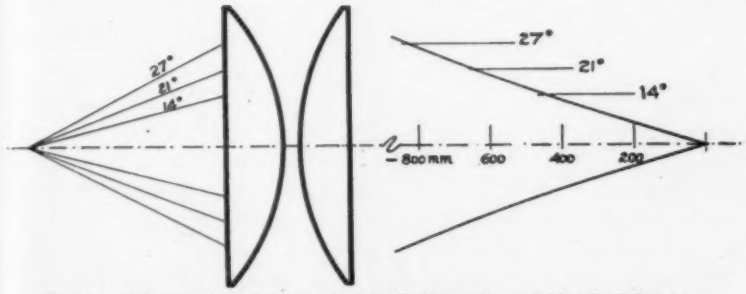

FIG. 3. *Spherical aberration curve for a projection condenser with spherical surfaces.*

The employment of a single parabolic surface in a two lens condenser construction leads to an enormous improvement. Fig. 3 shows the

enormous amount of spherical aberration residing in an uncorrected condenser and Fig. 4 the immense improvement accomplished by the use of one parabolic surface. These examples are of moderate numerical aperture. Another advantage of parabolic surfaces lies in permitting the attainment of numerical apertures absolutely impossible with spherical surfaces because of the limitation set by total reflection unless a larger number of surfaces is used.

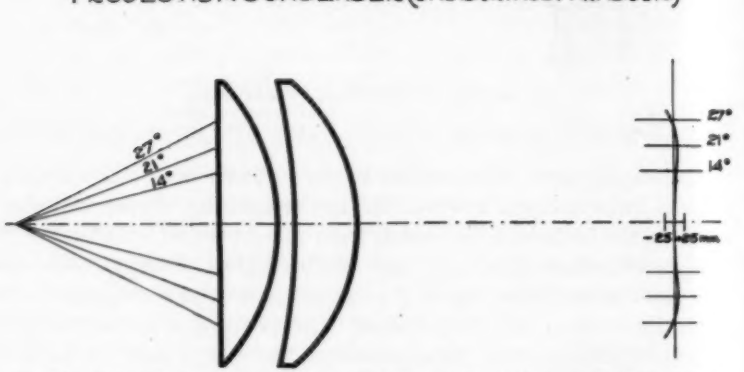

FIG. 4. *Spherical aberration curve for a projection condenser with one parabolic surface.*

The latest and most interesting application has been to a lens for motion picture photography. This work often demands the utmost speed possible in a lens. Particularly is this true in the case of photography in natural colors for which there are now at least three moderately successful processes. Until comparatively recent times a speed of f: 3.5 represented about the limit in astigmatically corrected lenses but we have recently designed an anastigmat with a speed of f: 2.7 which has been very satisfactory as to image quality. Still faster lenses, however, are demanded and because of our conviction that the speed f: 2.7 could not be exceeded by an anastigmat lens using spherical curves except, possibly, by very complex constructions we incorporated one parabolic surface in a three lens construction and succeeded thereby in securing excellent correction in a lens of f: 2.0.

One of the principal difficulties in the design of fast lenses lies in the correction of the spherical zones. Unless the zonal aberration can be kept below a certain minimum the general definition of the image can never be satisfactory. A comparison of Figs. 5 and 6 discloses the

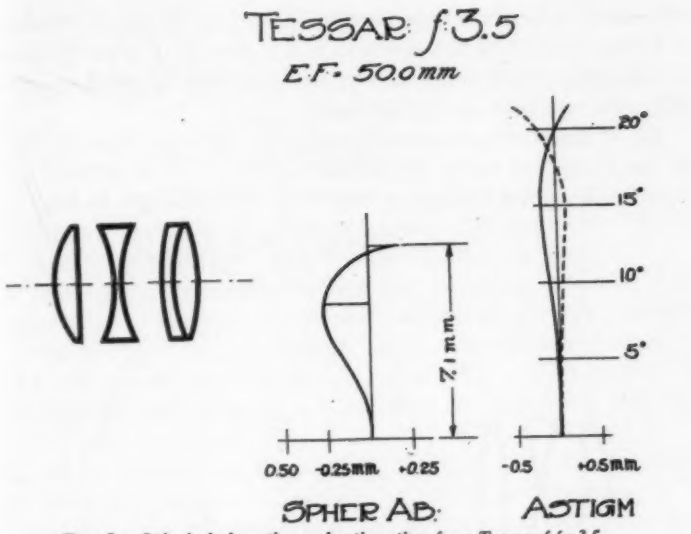

FIG. 5. *Spherical aberration and astigmatism for a Tessar of f : 3.5.*

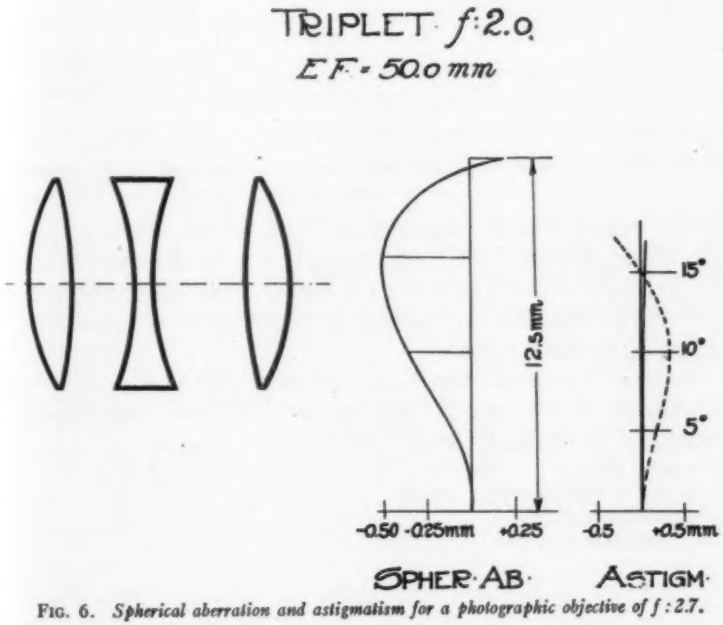

FIG. 6. *Spherical aberration and astigmatism for a photographic objective of f : 2.7.*

increase in spherical zones, in spite of our best efforts, in passing from f: 3.5 to f: 2.7. The lens shown in Fig. 6, in spite of a manifest increase in this respect still performs very satisfactorily but we have no doubt that this represents about the limit.

Fig. 7 illustrates the construction and shows the state of correction of the f: 2.0 lens using one parabolic surface. It is evident that the increase in spherical zones over the f: 3.5 lens shown in Fig. 5 is not

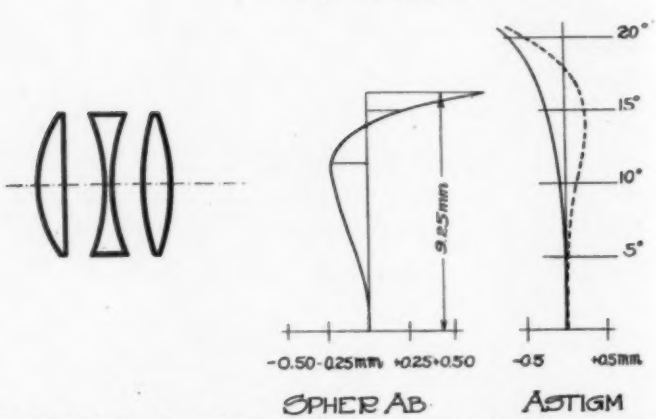

FIG. 7. *Spherical aberration and astigmatism for a photographic objective of f : 2.0 employing one parabolic surface.*

excessive and that it is better than in the f: 2.7 lens, while the correction for astigmatism is very good for a field of somewhat more than 30°. The correction of coma is of much the same degree of excellence in all three cases. We have been successful in making these lenses in focal lengths up to about 6 inches.

The lenses described above have been developed by Messrs. Bielicke and Rayton of the Scientific Bureau staff under the inspiration and guidance of Dr. Kellner, Chief of the Bureau.

SCIENTIFIC BUREAU
BAUSCH & LOMB OPTICAL COMPANY
ROCHESTER, N. Y.
SEPTEMBER 20, 1922.

NOTE ON PLATINUM RESISTANCE THERMOMETER CONSTRUCTION

By T. S. Sligh, Jr.

In an article entitled "On Construction of Platinum Thermometers and Resistance Coils" by J. R. Roebuck which appeared in the October (1922) issue of this Journal the following statement appears:

"Or consider the standard method of construction of platinum thermometers (ref.). The wire is wound in notches on the edges of four mica strips so that it makes a square. It is wound tight at room temperature. A rise in temperature . . . etc." The reference given is "(ref). See Summary by T. S. Sligh, Bur. of Standards Scientific Paper, No. 407."

The implication is that the method of construction cited typifies *present* standard construction as described in a recent publication of the Bureau of Standards, but as a matter of fact it is a description of a construction described by H. L. Callendar.[1] The variability of this type of thermometer caused it to be discarded long ago for high precision work.

The strain free construction now in use at the Bureau of Standards and described in detail in its publications[2] differs radically from the original Callendar Construction and was adopted over a decade ago for the express purpose of avoiding the strain incidental to the use of a tight winding on a rigid mica cross.

The necessity for this protest is to be regretted but it would be prejudicial to the extension of the use of platinum resistance thermometers as precision instruments to allow an implication that the art of their construction had not advanced in the past thirty years to stand unchallenged.

[1] Phil. Mag. *32*, p. 104, 1891.

[2] B.S. Bull. *6*, p. 120; 1909. B.S. Sci. Papers, No. 120.
B.S. Bull. *9*, p. 483; 1913. B.S. Sci. Papers, No. 200.
B.S. Bull. *17*, p. 49; 1921. B.S. Sci. Papers, No. 407.

TWENTY-FIFTH ANNIVERSARY CONVENTION OF THE AMERICAN CERAMIC SOCIETY

The "Silver Jubilee" convention of the American Ceramic Society was held in Pittsburgh Feb. 12-16, 1923. From an extensive program containing seventeen pages of titles of papers the following are of especial interest to the readers of this Journal:

A simple method of measuring color. . . . A. E. O. Munsell.
The resistance of soda lime glass to water. . . . L. A. Palmer.
A study of the tendency of glass to take up moisture. . . . K. L. Ford.
The advisability of pure research in glass in American Universities. . . Alexander Silverman.
Resistance of soda lime glass to water. . . . A. E. Williams.
Furnaces for the melting of glass in the laboratory . . . A. E. Badger and C. D. Spencer.
A study of the origin and cause of stones in glass. . . . Herbert E. Insley.
Results of mechanical tests on window plate and rolled sheet glass. . . . A. E. Williams.
Tensile strength of glass. . . . J. T. Littleton.
The meaning and microscopic measurement of average particle size. . . . G. St. J. Perrott.

A SIMPLE PRISM SPECTROGRAPH

By E. O. Hulburt

A spectrograph which satisfied in some degree the antagonistic requirements of high dispersion, ample light gathering power, small cost and simplicity of construction was obtained by mounting a glass prism in the Littrow manner. A diagram of the spectrograph is given in Fig. 1. The beam of light from the slit S, which is at the principle focus of the lens L, is directed to the lens by the small right angle prism R. The beam is rendered parallel by the lens and passes through the large 60° prism P. It is then reflected from the plane mirror M back again through the prism and lens. The spectrum is formed at T and may be viewed with an eye-piece or recorded on a photographic plate.

Fig. 1.

The lens was made of a single piece of glass 63 mm in diameter and of focal length 1 meter. The faces of the 60° glass prism were 50 mm square and those of the small right angle prism were 18 mm square. The lens and the two prisms were supplied from stock by the Bausch and Lomb Optical Company at a total cost of about thirty dollars. The mirror M, 80 mm square, was cut from a selected portion of ordinary plate glass and was plane within a wave-length of light as indicated by test with an optical flat. A reflecting layer of platinum was sputtered on to the glass.

The photographic performance of the spectrograph is demonstrated in Fig. 2. This shows spectrograms of the iron arc and of a condensed discharge through hydrogen at a pressure of 100 mm of mercury. The time of exposure to the hydrogen tube was about 5 seconds, with a slit width of about 0.02 mm, and to the iron arc a fraction of a second. Flat plates were used, curved ones would probably have given sharper lines at the ends of the spectrum. The visible spectrum was 65 mm in

length. The dispersion at 5000, 4000 and 3600 A.U. was approximately 40, 20, and 15 A.U. per mm, respectively.

Elaborate mountings of the optical parts of a Littrow spectrograph are described in the literature (see "Spectroscopy," E.C.C. Baly). In the present instance a modest design was carried out and was found to give every satisfaction. A wooden plank $60'' \times 11'' \times 2''$ served as the base. The slit S and the prism R were clamped to the base with adjustments in a vertical line and about a vertical axis. The parts L, P and M were firmly mounted on a wooden board $12'' \times 8'' \times 2''$ which could be moved by a screw adjustment along the base for the purpose of focussing. The lens L was clamped in place being tilted slightly to throw out of the field of observation the light reflected directly from its surfaces. The prism P was set at minimum deviation for wavelengths in the center of the spectrum and was clamped firmly with

FIG. 2.

no subsequent readjustment for the other regions of the spectrum. The mirror M was held in a ball-and-socket type of adjustment so that any desired portion of the spectrum could be directed into the field of view of the eye piece or on to the photographic plate. Although a metal frame work is in general preferable, the wooden mounting was found to possess sufficient rigidity and permanence of adjustment. An achromatic lens at L instead of the singlet lens would enable greater ease of focussing but the advantage gained would often not be worth the greater expenditure. Higher dispersion could be attained by the use of a longer focus lens or by the introduction of a second 60° prism, the second method giving a spectrum of greater brilliancy than the first.

PHYSICAL LABORATORY,
UNIVERSITY OF IOWA,
NOVEMBER, 1922.

REVIEWS

The Origin of Spectra. By Paul D. Foote and F. L. Mohler. Amer. Chemical Society Monograph Series. Pp. 250. The Chemical Catalog Co., New York, 1922.

This is a very valuable contribution to modern spectroscopy. Pre-eminently experimental by design, and yet in incessant contact with theoretical considerations, this volume is, on the one hand, a much desirable supplement to Sommerfeld's well-known book on Atomic Structure and Spectrum Lines. On the other hand it excels over the latter in two respects: first, by being less enthusiastic and therefore more critically reserved with regard to the prospective extension of the triumphs of Bohr's theory to the domain of non-hydrogenic spectra and of the corresponding atomic models; second, by describing a wealth of well selected and refreshing experimental problems, solved as well as unsolved, and thus giving the reader, in almost every section, some good stimulus to new thought and to promising experimental research. The circumstance that a conspicuous part of the experimental results described is due to the authors themselves was visibly helpful in the attainment of this precious feature of the book.

Chapter I. gives, in spite of the mainly experimental tendency of the publication, a fairly complete theoretical introduction to the subject, "The Quantum Theory of Spectroscopy," in a clear exposition and an attractive form. The application of Sommerfeld's ring models, through formula (53), p. 41, to the comparison of spectra, though leading to remarkable coincidences in Table VII, could profitably be treated more critically in view of the avowedly unsatisfactory nature of such models (cf. Sommerfeld, loc. cit., 3rd ed., especially p. 725). But this is after all a minor point, in the present connection at least, and it may safely be said that the chapter will be very helpful to all beginners. The authors close the first chapter, containing good tables and some instructive figures, with a purposely naive ornamental flourish consisting of a Langmuir cube-model of neon interlaced with its planetary rival-model. But the spectre of a shadowy interrogation sign hanging over both models testifies sufficiently to the soundly sceptical attitude of the authors with regard to our knowledge of the intra-atomic configuration of electrons.

The Energy Diagrams given in Chapter II, illustrating the concept of energy levels and its application, will be found very useful, and are, in fact, used extensively in the following chapter on Ionization and Resonance Potentials for the Elements, and throughout the book. We have next two very valuable chapters on Absorption—and on Emission Line Spectra of Atoms, including resonance radiation and a number of other important subjects of recent (and of outstanding) spectroscopic research. Chapter VI treats of the mathematically and experimentally interesting subject of ionization of atomic systems by successive stages of excitation, and the next chapter is devoted to Thermal Excitation, a subject of quite recent origin and most interesting for the terrestrial as well as the solar physicist and for the student of stellar evolution. The subjects here treated, and essentially based on sound thermodynamical considerations, were thus far accessible only through scattered special papers, and everybody will be grateful to the authors for gathering them together into a lucid and systematic presentation.

Chapter VIII is devoted to Thermochemical Relations, to wit, the electron-affinity of atoms as revealed spectroscopically or through "grating energy" (space-lattice energy, Born) and from ionization potentials. Here also the question of ionization of compounds,

as vapors, is treated; the accompanying table (p. 188) contains many interesting numerical results concerning such molecular compounds, a good number of these data being due to the authors. The first of the remaining three short chapters gives a rapid, yet very instructive account of X-ray Spectra, the second treats of the Photo-electric effect in Vapors, and the third and last chapter of the book gives a short account of the determinations of Planck's radiation constant h involving line spectra.

The volume closes with two Appendices, one containing a good selection of computational data, including a handy periodic table of the elements, and another, giving a condensed review of Bohr's recent, largely conjectural, ideas on Atomic Structure, a subject which is rather of the nature of a programme whose accomplishment may require several generations. The authors are well aware of the prematurity of Bohr's last publication, as will be manifest from the justly critical tenor of the Conclusion of this appendix.

After what has been said above in some detail it is scarcely necessary to add that Foote and Mohler's excellent book can be warmly recommended to every student of spectroscopy.

L. SILBERSTEIN.

ROCHESTER, N. Y.
NOVEMBER, 1922.

NOTICES

OPTICAL SOCIETY OF AMERICA

Minutes of the Executive Council

Meetings of the Executive Council were held in connection with the Seventh Annual Meeting, Washington, D. C., as follows: October 25th, Cosmos Club; October 26th, Bureau of Standards; October 27th, Bureau of Standards. Present at all meetings: Troland, Ives, Priest, Southall, Foote, Richtmyer, Ames and Forsythe. A letter from Mr. Lomb was read stating his views on a number of the subjects before the Council.

The following is a digest of the Council's actions at these meetings.

Election of Members

Honorary

No. 331 A. A. Michelson, University of Chicago, Chicago, Ill.
No. 332 S. W. Stratton, Bureau of Standards, Washington, D. C.

Regular

No. 333 Horace L. Howes, New Hampshire State College, Durham, N. H.
No. 334 Louis Williams McKeehan, 463 West Street, New York City.
No. 335 Harlan True Stetson, Astronomical Laboratory, Harvard University, Cambridge, Mass.
No. 336 Louis Bell, 120 Boylston Street, Boston, Mass.
No. 337 Janet Howell Clark, 232 W. Lanvale Street, Baltimore, Md.
No. 338 Bassett Jones, 101 Park Avenue, New York City.
No. 339. E. J. Brady, 3101 Passyunk Avenue, Philadelphia, Pa.
No. 340. John Fred Mohler, 127 South College Street, Carlisle, Pa.
No. 341 Franklin L. Hunt, Bureau of Standards, Washington, D. C.
No. 342 Otto Stuhlman, Jr., University of North Carolina, Chapel Hill, N. C.
No. 343 George K. Burgess, Bureau of Standards, Washington, D. C.
No. 344 F. C. Brown, (Reinstatement), Bureau of Standards, Washington, D. C.

Associate

No. 345 Horatio B. Williams, College of Physicians & Surgeons, Columbia, University, New York City.
No. 346 Daniel O. Landis, 625 North 10th Street, Philadelphia, Pa.
No. 347 Henry D. Hubbard, 112 Quincy Street, Chevy Chase, Md.
No. 348 Harold Frederic Stimson, Bureau of Standards, Washington, D. C.
No. 349 Edison Pettit, Mount Wilson Observatory, Pasadena, Calif.
No. 350 Roger H. Sinden, Johns Hopkins University, Baltimore, Md.
No. 351 J. M. McCallie, 822 Berkeley Avenue, Trenton, N. J.
No. 352 Elmer E. Hotaling, 9 East 46th Street, New York City.
No. 353 Emory Hill, 501 East Franklin Street, Richmond, Va.
No. 354 Howard O. Stearns, P. O. Box No. 419, Rochester, Minn.

In connection with the election of Dr. Stratton to honorary membership, the following resolution was adopted:

Whereas, The By-Laws of the Optical Society of America provide that "Any person who has done eminent service in the advancement of optics is eligible to honorary membership," and

Whereas, it is the unanimous opinion of the Executive Council of the Optical Society of America that Dr. Samuel Wesley Stratton, Director of the

National Bureau of Standards, has performed such an eminent service in the systematic and consistent encouragement and cultivation of research in pure and applied optics during the twenty-one years of his wise and able administration of the National Bureau of Standards, and

WHEREAS, The Executive Council of the Optical Society of America desires to express its appreciation of Dr. Stratton's administration and desires to record and publicly acknowledge the eminent service which he has performed in the advancement of optical research in America, therefore be it

RESOLVED, That Dr. Samuel Wesley Stratton is unanimously elected an Honorary Member of the Optical Society of America.

TIME AND PLACE OF NEXT ANNUAL MEETING OF THE SOCIETY

On the invitation from Cleveland, communicated by Dr. W. E. Forsythe, the Council fixed the Eighth Annual Meeting to be held in Cleveland, in October, 1923.

EDITOR FOR THE TRANSLATION OF HELMHOLTZ' PHYSIOLOGIC OPTICS

Prof. J. P. C. Southall was selected as editor-in-chief for the translation of Helmholtz' Physiologic Optics.

ACTIONS RELATIVE TO THE ORGANIZATION OF COMMITTEES AND THE PUBLICATION OF THEIR REPORTS

The following resolutions were adopted:

"WHEREAS, It is important to the Society that published Committee reports truly represent the consensus of opinion of the Society's recognized experts in the various subjects of committee reports, and

WHEREAS, It is important that responsibility for such reports be definitely lodged,

RESOLVED that, (1) it shall be the duty of the president to file with the Secretary and with the Editor of the JOURNAL, not later than January 10th of each calendar year certified lists of the complete personnel of all duly appointed committees for the current calendar year; (2) it shall be the duty of the President to promptly notify the Secretary and the Editor of any changes in said committees during the year; (3) it shall be the duty of the Editor to publish this list and corrections to it in the JOURNAL at the earliest possible date; (4) beginning with the issue for January, 1923, it shall be the duty of the Editor to decline to publish under the caption of "Committee Report" any contribution not bearing the actual signatures of a majority of the members of the Committee; (5) if the report does not bear the signatures of all members of the Committee, it shall further be the duty of the Editor to submit the manuscript to each member who has not signed and to append to each such published report, a note giving the complete personnel of the committee and, if desired by any of them, a statement of his dissent from the report."

RESOLVED, That hereafter the Committees hitherto known as the "Committees on Nomenclature and Standards," shall be designated as "Committees on Progress."

RESOLVED, That the following footnote be appended to every report of a committee on progress which is published in the official organ of the Optical Society of America, to wit: "The publication of progress committee reports does not imply that they are officially adopted by the Optical Society of America."

The resolution adopted May 4th, 1922, to wit:

"RESOLVED, That the printed reports of the sub-committees of the Optical Society committee on nomenclature and standards shall be advertised in the

JOURNAL as for sale at a price per copy depending upon the number of pages, the number of such reprinted reports and price to be determined by the publication committee, and the proceeds of such sales to go to the treasury of the Optical Society."

was repealed.

ACTIONS RELATIVE TO PAPERS TO BE PRESENTED AT ANNUAL MEETINGS

VOTED: That the President be authorized and requested to appoint a Committee on Papers for each annual convention.

RESOLVED: That it is the sense of the Council that ordinarily, members should not present, without invitation, papers which have already been published.

AMENDMENTS TO THE BY-LAWS

The following amendments to the By-Laws were adopted:

Art. IV, Sec. 3, was amended to read:

"Election shall be by ballot. Nominations shall be made by a nominating committee appointed by the president and approved by the Council. This committee shall consist of five regular members of the society, at least one of whom shall be a past president of the Society."

Art. I, Sec. 3, was amended to read:

"Election to Membership. All applications for membership shall first be considered as applications for associate membership and acted upon as such. Applicants shall be deemed elected to associate membership when their duly prepared applications have received the written approval of three members of the Executive Council.

Elections to regular membership shall be made only by the Executive Council in annual meeting.

Associate members may be elected to regular membership when favored with the vote of two-thirds of the members of the Executive Council present and voting.

The Executive Council may elect honorary members by unanimous vote."

ACTION RELATIVE TO DELINQUENT MEMBERS

RESOLVED, That the Council authorizes the Secretary to strike from the membership list, the names of all members who are certified by the Treasurer to be in arrears one year or more, as provided in the By-Laws.

ACTIONS RELATIVE TO THE JOURNAL

RESOLVED, That it is the unanimous opinion of the Council of the Optical Society of America that the expenditure of funds accruing to the Journal of the Optical Society of America and Review of Scientific Instruments, under the contract between the Optical Society of America and the Association of Scientific Apparatus Makers, shall be made by agreement between the Editor-in-chief, the Assistant Editor-in-chief and Business Manager, and the Consulting Business Manager.

VOTED, That F. K. Richtmyer and H. E. Ives be appointed a Committee to consider the question of abstracts of JOURNAL articles.

[Signed] IRWIN G. PRIEST, *Secretary.*

Submitted to all members of Council by mail Nov. 1, 1922.

Approved, Nov. 17, 1922.

[Signed] L. T. TROLAND, *President.*

The Physical Society of London and the Optical Society held their thirteenth annual exhibit of electrical, optical, and other physical apparatus at the Imperial College of Science, South Kensington, on the 3rd and 4th of January. Engineering for January 5th, 1923, contains the first installment of a detailed account of the event. The account deals almost exclusively with the exhibits of the Cambridge and Paul Instrument Company and the instruments described are primarily electrical. A high speed oscillograph camera developed from drawings furnished by the U. S. Bureau of Standards is among the instruments exhibited and described. Other instruments described are the Odén-Keen balance for recording sedimentation, the Moulin device for measuring small high-frequency voltages, a valve generator of audio-frequency alternating currents, and two types of electrically maintained tuning forks.

E. A. ECKHARDT

Earth Inductor Compass. P. R. Heyl and L. J. Briggs. Proc. Am. Phil. Soc., Vol. 61, No. 1, 1922.

This instrument has been developed with especial reference to vessels for the navigation of the air. It possess five novel features not found in earlier attempts along the same line.

(1) It employs a null method for its indications, and therefore enjoys all the advantages of sensitivity characteristic of null methods as a class. As long as the vessel lies in the course predetermined by the pilot no deflection is produced in the galvanometer.

(2) A course-setting device of a novel type is employed. By turning a movable dial carrying compass graduations to the desired course mark, the electrical connections are so made that the galvanometer will read zero only when the vessel is in the desired line. This device enables the pilot to control a compass situated at a safe distance from mechanical disturbances without the use of a mechanical connection.

(3) The pilot is able to distinguish between the two opposite directions which the vessel may take in any line.

(4) A method is provided for eliminating the errors due to rolling and pitching.

(5) By the judicious use of iron in the case of the coil the size of the earth inductor may be greatly reduced and the output increased without the introduction of any sensible error.

Air tests have shown that the instrument can be read to about 2 or 3 degrees during rolling and pitching of the airplane. The total weight of the apparatus is about 12 pounds. The rotating part is installed in the rear part of the fuselage, at a distance from the engine, the principal source of magnetic disturbance.

P. R. HEYL